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Canada, Mines, Bureau of

CANADA  
DEPARTMENT OF MINES

MINES BRANCH

HON. W. TEMPLEMAN, MINISTER; A. P. LOW, LL.D., DEPUTY MINISTER;  
EUGENE HAANEL, PH.D., DIRECTOR.

AN  
INVESTIGATION  
OF THE  
COALS OF CANADA

WITH REFERENCE TO THEIR ECONOMIC QUALITIES:

AS CONDUCTED AT MCGILL UNIVERSITY, MONTREAL,  
UNDER THE AUTHORITY OF THE DOMINION  
GOVERNMENT

IN SIX VOLUMES

[and Extravol.]

BY

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THE  
COALS OF CANADA:  
AN ECONOMIC INVESTIGATION

VOL. VI

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APPENDIX IV  
MANUFACTURE AND TESTING OF COKE  
BY  
EDGAR STANSFIELD AND J. B. PORTER

APPENDIX V  
WORK OF THE CHEMICAL LABORATORY  
BY  
EDGAR STANSFIELD



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# THE COALS OF CANADA: AN ECONOMIC INVESTIGATION

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VOL. VI

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## INTRODUCTORY

In the autumn of 1906, the Canadian Government, through Dr. A. P. Low, Director of the Geological Survey, decided to undertake a study of the fuels of the Dominion, somewhat on the lines of the fuel tests which had already been commenced by the United States Geological Survey. But inasmuch as the Government had not, at Ottawa, any suitable mechanical laboratories, and as research work had already been done by the Mining Department of McGill University on a number of western coals, Dr. Low invited Dr. Porter, the head of that department, to undertake the larger investigation. This proposal was approved by the University governors, and Dr. Porter was authorized to carry out the tests in the University laboratories, without charge; on the understanding that the Government would pay for such apparatus as might be required to supplement the existing equipment, and to make good all additions to the salaries, wages, and supplies accounts, rendered necessary by the investigation. At the request of Dr. Low, also, the Intercolonial and Canadian Pacific railways very generously agreed to haul the material—amounting to many hundreds of tons—free of charge.

Shortly after the commencement of the investigation the Dominion Department of Mines was created, under the Hon. William Templeman, as Minister of Mines, and Dr. A. P. Low, as Deputy Minister; and the investigation, together with all matters relating to economic minerals, was transferred from the Geological Survey to the Mines Branch, under the Directorship of Dr. Eugene Haanel. The original arrangement was, however, in all other respects, continued without change.

From the beginning it was intended to confine the investigation to the coals and lignites of the Dominion; and the following points were covered by the scheme:—

- Sec. I.—General organization and administration.
- Sec. II.—Preparation of a general summary report on Canada's coal fields and coal mines.
- Sec. III.—Sampling in the field.
- Sec. IV.—Crushing the samples and preparing them for treatment.
- Sec. V.—Washing and mechanical purification.
- Sec. VI.—Coking trials.
- Sec. VII.—Steam boiler trials.
- Sec. VIII.—Producer, and gas engine trials.
- Sec. IX.—Chemical laboratory work, and miscellaneous investigations.

## TECHNICAL STAFF.

The technical staff engaged in the investigation, comprised:—

- (1). J. B. Porter, E.M., Ph.D., D.Sc., Professor of Mining Engineering, McGill University—Responsible for the organization and general direction of the investigation, and directly in charge of Sections I, IV, and V, and VI (in part).
- (2). R. J. Durley, B.Sc., Ma.E., Professor of Mechanical Engineering, McGill University—In charge of Sections VII and VIII.
- (3). Théo. C. Denis, B.Sc., Mines Branch, Department of Mines, Ottawa—In charge of Sections II and III (in part).
- (4). Edgar Stansfield, M.Sc., Chief Chemist—In charge of Section IX, and Sections III and VI (in part).
- (5). H. F. Strangways, M.Sc., Dawson Fellow in Mining, McGill University—Assistant in Sections IV and V 1907.
- (6). H. G. Carmichael, M.Sc., Dawson Fellow in Mining, McGill University—Assistant in Sections IV and V 1908.
- (7). E. B. Rider, B.Sc., Demonstrator in Mining, McGill University—Assistant in Sections IV and V 1909-10.
- (8). Chas. Landry, Chief Mechanic of Mining Department, McGill University—Foreman in Sections IV and V.
- (9). J. W. Hayward, M.Sc., Assistant Professor of Mechanical Engineering, McGill University—Assistant in charge of Section VII 1907, and preliminary work in Section VIII.
- (10). J. Blizzard, B.Sc., Lecturer on Mechanical Engineering, McGill University—Assistant in charge of Section VII 1908, and Assistant in Section VIII.
- (11). D. W. Munn, M.A., B.Sc., Demonstrator in Mechanical Engineering, McGill University—Assistant in Sections VII and VIII.
- (12). G. L. Guillet, M.Sc., Demonstrator in Mechanical Engineering, McGill University—Assistant in Section VII.
- (13). G. Killam, M.A., B.Sc., Demonstrator in Mechanical Engineering, McGill University—Assistant in Section VIII.
- (14). J. S. Cameron, B.Sc., Demonstrator in Mechanical Engineering, McGill University—Assistant in Section VIII.
- (15). A. Balmfirth, Superintendent of McGill University Power House—Foreman in Section VII.
- (16). J. Gardner, Foreman in Section VIII.
- (17). J. Hoult, Fireman in all tests of Section VII.
- (18). J. H. H. Nicolls, B.Sc., Assistant Chemist—Assistant in Section IX 1908, 1909.
- (19). R. T. Mohan, B.Sc., Assistant Chemist—Assistant in Section IX 1908.
- (20). P. H. Elliott, M.Sc., Assistant Chemist—Assistant in Section IX 1908.

(21). E. J. Conway, B.Sc., Assistant Chemist—Assistant in Section IX 1908.

(22). W. B. Campbell, Assistant Chemist—Assistant in Section IX 1909.

(23). R. S. Boehner, M.Sc., Demonstrator in Chemistry, McGill University—Assistant in Section IX 1908, 1909.

(24). H. Hartley, B.Sc., Assistant Chemist—Assistant in Section IX 1909.

(25). W. B. Meldrum, B.Sc., of the Department of Chemistry, McGill University—Assistant in Section VI 1909.

(26). H. H. Gray, B.Sc., Demonstrator in Metallurgy, McGill University—Assistant in Section VI 1909.

(27). H. G. Morrison, B.Sc., Assistant Chemist—Assistant in Section IX, 1909, 1910.

There were also a number of machinists, mechanics, and labourers, engaged more or less continuously in the several sections.

In addition to the persons above named, the following members of the University staff very materially aided in the progress of the work by giving occasional assistance and advice:—

Alfred Stansfield, D.Sc., Professor of Metallurgy.

H. T. Barnes, D.Sc., Professor of Physics.

Acknowledgment is also due to the Governors of McGill University, and to W. Peterson, C.M.G., Principal; F. D. Adams, F. R. S., Dean; W. Vaughan, Esq., Secretary; S. R. Burrell, Esq., Chief Accountant, and many others.

#### LABORATORIES.

The laboratories of the Mining and Mechanical Departments of McGill University, in which the tests were made, were built and equipped some few years ago on a scale unequalled at the time in North America, the buildings and apparatus for the Ore Dressing Department alone costing over \$150,000, and the Steam Laboratory an almost equal sum. This equipment needed very little augmentation in respect of sampling, crushing, coal washing, steam boiler tests, and chemical analysis; although a number of minor pieces of apparatus had to be purchased, such as extra calorimeters, pyrometers, thermometers, etc., etc.

In the matter of producer and gas engine tests, larger expenditure was necessary, as the University equipment was on too small a scale for the extensive tests contemplated. An addition  $25 \times 70$  was, therefore, built to the Ore Dressing Laboratory, and equipped with a complete plant of the most modern type, the cost for building and plant being approximately \$12,000. A detailed description of this plant, with cuts of the apparatus, etc., will be found in Vol. II, Part VIII of the report, and similar descriptions of the apparatus used in the other parts of the investigation will be found in the other parts.

## THE INVESTIGATION.

*Sampling in the field.*

Sixty-three separate mines or seams were specially sampled for the investigation. The work of sampling was always done by a responsible member of the technical staff, and every precaution was taken to ensure reliability. The general rules governing this sampling and the detailed descriptions of the work of sampling at the several mines are fully stated in Vol. I, Part III.

A list of the samples arranged in geographical order is given in the table of contents of each volume of the appendices III, IV, and V, and is printed in the text of the Report proper, Vol. I, pp. 8 to 11 and Vol. II, pp. 181 to 184; also in this Vol., pp. 17 to 20.

*Crushing and Sampling in the Laboratory.*

The main samples on their arrival at the testing plant at McGill University were all crushed to go through a 2" screen, mixed thoroughly on a large granolithic sampling floor, sampled for the chemist, etc., and finally resacked, sealed, and sent to a dry room for storage while awaiting test.

The methods of sampling are stated in detail in Vol. I, Part IV.

The smaller subsidiary samples were sent directly to the chemical laboratory, where they were stored in sealed vessels until required.

*Mechanical Purification.*

Each main sample was experimentally treated in the laboratory with heavy solutions, and the fractions analysed with a view to determining the probable results of washing. In all cases where these preliminary tests gave favourable results, a large lot was treated in the coal washing plant of the University, and this work was checked by a further series of tests with heavy solutions.

It would, of course, be possible in a laboratory to do extremely thorough washing at an expense disproportionate to the value of the coal; but this was not attempted, the aim being to reproduce commercial conditions. From comparative tests made between laboratory work and coal washing in standard plants, it is evident that this end has been attained, and the tests as carried on may be taken in a broad way to represent average commercial work.

The whole subject of coal washing as well as testing is dealt with in Vol. I, Part V, and the results of all the trials are presented in a series of summary tables. The detailed results of each test are given in Volume III.

*Coking Trials.*

The determination as to whether or not any particular coal will make a good coke is of great practical importance, and until recently it has been considered impossible without first conducting a series of oven trials on a large and costly scale. Even a single full sized experimental oven is unsatisfactory for such work, as its operation differs much from that of an oven surrounded by its fellows; and as a result the only safe course has been to send a very considerable quantity of each coal to be tested to a bank of ovens and to test it under standard conditions, repeating the operation if necessary with different coking periods until a definite conclusion can be reached.

It was obviously impossible to carry out complete tests of the above character on all of the fifty odd coals in the series under consideration, and, therefore, an extended investigation was undertaken at the coking plant of the Dominion Iron and Steel Co. at Sydney, N.S., with a view to developing some reliable method of working on a small scale. These experiments, supplemented by tests in various types of oven in different places in Canada, finally led to a satisfactory conclusion, and it is now possible to test coals in lots of say 50 pounds, the resultant cokes being in every way similar to those produced in commercial ovens and in most cases indistinguishable from them.

The method in brief is as follows: the sample of coal, which should be as fresh as possible, is crushed, washed if necessary, and slightly moistened in some cases, and thus brought to exactly the conditions in which it would normally go to the oven. It is then put in rectangular boxes of heavy sheet iron, each holding say 50 pounds. These boxes are freely perforated to permit of the escape of gas, but the perforations are blanked with paper to prevent the egress or ingress of coal. The boxes are weighed and placed in an oven which is being charged, and become, in fact, a part of its regular charge and are coked under perfectly normal conditions. On the withdrawal of the charge, the boxes are quenched as promptly yet as lightly as possible, and are then dried and weighed before being opened.

In addition to the straightforward trials to determine whether the several coals would or would not coke, a series of tests was made to determine the effect of moistening, compressing, etc., and of different temperatures and durations of the coking period.

A method had to be devised also to determine the strength of the cokes produced. Mere crushing tests do not suffice, and it was finally decided to adopt a standard method of testing in a tumbler to determine the losses in handling, and of crushing to a fixed pressure in bulk to determine strength in coke bins and furnaces.

Another series of tests was made to determine the effect of weathering on coal before using it for coke production. Some coals will coke only when quite fresh; others will coke, but not so well, when stale; still others

do not seem to be affected even by comparatively long exposure to the air. The whole matter is somewhat obscure and chemical analysis does not cast as much light on it as one could wish.

The subject of coking, as well as the testing of coking qualities, is dealt with in Vol. I, Part VI, and the results of all of the main trials are presented in a series of summary tables. The detailed results of the tests and the full records of a number of subsidiary tests are given in Appendix IV of the present volume.

### *Boiler Trials.*

The boiler trials were conducted in the boiler testing room of the University, the method used being as far as possible in accordance with standard practice.

The boiler, which is a Babcock and Wilcox, rated at 60 H.P., was thoroughly cleaned and tested before the trials were commenced, and standardizing tests were run with Georges Creek coal. The series included 72 trials, each of which lasted at least ten hours.

The methods employed in conducting the trials are fully detailed in Vol. II, Part VII, and this part also contains a general discussion of the use of coal for steam raising, and a tabular summary of the whole series of trials.

Full notes of each of these trials are published in Vol. IV, Appendix II, followed by the summary record above referred to reprinted from Vol. II.

### *Producer Trials.*

The producer trials were made in a special laboratory erected and equipped for the purpose at McGill University. Several producers were tested, but the standard trials were carried out in a special down-draught producer rated at 40 H.P.

The trials lasted at least 24 hours, and were checked by longer runs—one of 10 days.

The methods employed in conducting the trials are fully set forth in Vol. II, Part VIII, and the results of the trials are presented in tabular form. This Part also contains a discussion of general questions of the use of producers and gas engines for the generation of power. The detailed results of the trials are contained in Vol. V, Appendix III.

### *Chemical Laboratory.*

The work that had to be done in the Chemical Laboratory was very considerable. Methods and apparatus had to be devised, tested, and standardized, and all materials, whether raw, intermediate, or final products,

had to be analysed. No count of the total number of analyses made has ever been made, but a mere enumeration of the different materials analysed and of the different analyses, determinations, and investigations carried out will give some idea of the extent of the work done.

#### MATERIALS ANALYSED.

*Coal Samples*—main, mine, weathering, boiler trial, gas producer tests, coking tests, final washed coal, separate products of washery, specific gravity tests, screen analyses, etc. *Coke samples* from coking tests: *gas samples* from boiler trials, gas producer tests and coking tests: *ash samples* from boiler trials, gas producer tests, and laboratory combustion of raw and washed coal.

#### CHEMICAL DETERMINATIONS MADE.

Carbon, hydrogen, oxygen, sulphur, nitrogen, moisture, ash, volatile matter, fixed carbon, combustible matter, carbon dioxide, carbon monoxide, ethylene, methane.

#### PHYSICAL DETERMINATIONS MADE.

Fusion temperature of ashes, specific gravity, porosity and strength of cokes, calorific values of solid and gaseous fuels.

#### SPECIAL INVESTIGATIONS.

Special investigations have been made on the determination of sulphur in coal, determination of volatile matter in coal and coke, solubility of coal in water, determination of physical values of coke, weathering of coal, etc. An investigation is also being carried out on the spontaneous combustion of coal in storage, but as this is in addition to the original research and is being supported by private contribution, it is intended to insert only a preliminary article here and to submit the full results in a special supplementary report to be published as soon as possible after the present volume.

The regular methods of analysis adopted in the routine tests are described and discussed in Vol. II, Part IX, in connexion with a series of tables giving a summary of the analyses of all of the coal samples.

A large amount of additional matter is presented in Appendix V of the present volume, the separate papers including discussions of some of the special investigations preliminary to the adoption of the standard methods and detailed descriptions of several subsidiary investigations.

## THE REPORT.

It will be seen from the above description of the investigation that an attempt has been made to cover a large field, and yet to do the work in great detail. As a result of this, a very large amount of information has been gathered; but much of it is so highly technical as to be only of interest to specialists, hence it has been thought best to divide the Report—which comprises six volumes—into two main sections, of two and four volumes respectively.

In the first section there are separate chapters, or parts, dealing with each of the seven divisions of the investigation outlined in the last few pages. Each of these parts begins with an introduction in which the subject of the division is dealt with in a general way, followed by a more or less extended description and discussion of the experimental work attempted; and concluding with a carefully tabulated summary of all of the tests in that division.

Preceding the technical reports referred to above there are two important chapters, the first being an introduction dealing with the investigation as a whole, and the second being a very full descriptive paper on the history, geology, and present commercial development of the coal fields and coal mines of Canada, from the pen of Mr. Théo. C. Denis—a member of the permanent staff of the Mines Branch of the Department of Mines. This part of the Report, which is profusely illustrated with maps and photographs, differs from the remainder in that its matter is largely drawn from previous publications of the Geological Survey and other sources, but it possesses great value as an introduction to the somewhat technical reports which follow, and is of importance, on its own account, as the most complete work yet written on the coal fields of the Dominion.

The first two volumes of the Report, comprising Parts I to IX inclusive, may, therefore, be considered as complete in themselves, and it is hoped that they will prove of value not only as contributions to the technological literature on coal, but also as a source of useful and timely information to the general public, on the coal resources of the Dominion and on the best methods of utilizing these resources.

The remaining four volumes, III, IV, V, and VI,<sup>1</sup> are given up exclusively to tabulated records and details of the tests summarized in Volumes I and II, to which they thus become highly technical appendices.

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<sup>1</sup> Inasmuch as Mr. Edgar Stansfield became a member of the permanent staff of the Mines Branch, and hence had new duties to perform prior to the completion of the reports on the sections with which he was connected, it was necessary for him to write nearly the whole of Part IX and of Vol. VI in his private time; and, on account of Civil Service regulations, without remuneration. This has resulted, unavoidably, in the omission from Vol. VI of any account of several minor investigations and the abbreviation of certain parts.

## LIST OF COALS TESTED.

*Sydney Coal Field, Cape Breton Co., N.S.*

- No. 50<sup>1</sup>—Gowrie seam, North Atlantic Collieries, Ltd., Port Morien, N.S.
- No. 36—Dominion No. 7. Hub seam, Dominion Coal Co., Ltd., Glace Bay, N.S.
- No. 35—Dominion No. 9. Harbour seam, Dominion Coal Co., Ltd., Glace Bay, N.S.
- No. 35 SP.—Dominion No. 5. Phalen seam, Dominion Coal Co., Ltd., Glace Bay, N.S.
- No. 38—Dominion No. 1. Phalen seam, Dominion Coal Co., Ltd., Glace Bay, N.S.
- No. 37—Dominion No. 10. Emery seam, Dominion Coal Co., Ltd., Glace Bay, N.S.
- No. 39—Dominion No. 12. Lingan seam, Dominion Coal Co., Ltd., Glace Bay, N.S.
- No. 13—No. 1 Colliery, Nova Scotia Steel and Coal Co., Ltd., Sydney Mines, N.S.
- No. 12—No. 3 Colliery, Nova Scotia Steel and Coal Co., Ltd., Sydney Mines, N.S.

*Inverness Coal Field, Inverness Co., N.S.*

- No. 14—Inverness Colliery, Inverness Railway and Coal Co., Inverness, N.S.
- No. 15—Port Hood Colliery, Richmond Railway Coal Co., Ltd., Port Hood, N.S.

*Pictou Coal Field, Pictou Co., N.S.*

- No. 4—Six foot seam, Vale Colliery, Acadia Coal Co., Ltd., New Glasgow, N.S.
- No. 16—Foord seam, Allan Shaft Colliery, Acadia Coal Co., Ltd., Stellarton, N.S.
- No. 1—Third seam, Albion Colliery, Acadia Coal Co., Ltd., Stellarton, N.S.
- No. 2—Cage Pit seam, Albion Colliery, Acadia Coal Co., Ltd., Stellarton, N.S.
- No. 8—Main seam, Acadia Colliery, Acadia Coal Co., Ltd., Westville, N.S.
- No. 3—Main seam, Drummond Colliery, Intercolonial Coal Mining Co., Ltd., Westville, N.S.

*Springhill Coal Field, Cumberland Co., N.S.*

- No. 49—No. 1 Colliery, Cumberland Railway and Coal Co., Ltd., Springhill, N.S.

<sup>1</sup> The distinguishing numbers of the coal samples were arbitrarily assigned at the time, and have been retained for convenient reference. They have no other significance.

No. 5—No. 2 Colliery, Cumberland Railway and Coal Co., Ltd., Springhill, N.S.

No. 6—No. 3 Colliery, Cumberland Railway and Coal Co., Ltd., Springhill, N.S.

*Joggins-Chignecto Coal Field, Cumberland Co., N.S.*

No. 7—Chignecto Colliery, Maritime Coal, Railway, and Power Co., Ltd., Chignecto, N. S.

No. 9—Minudie Colliery, Minudie Coal Co., Ltd., River Hebert, N.S.

No. 10—Joggins Colliery, Canada Coals and Railway Co., Ltd., Joggins, N.S.

*Grand Lake Coal Field, Queens Co., N.B.*

No. 11—King's Mine, G. H. King, Minto, N.B.

*Souris Coal Field, Sask.*

No. 40—Western Dominion Collieries, Ltd., Taylorton, Sask.

No. 41—Eureka Coal and Brick Co., Ltd., Estevan, Sask.

*Edmonton Coal Field, Alta.*

No. 46—Strathcona Coal Co., Ltd., Strathcona, Alta.

No. 42—Parkdale Coal Co., Ltd., Edmonton, Alta.

No. 45—Standard Coal Co., Edmonton, Alta.

*Belly River Coal Field, Alta.*

No. 43—Canada-West Coal Co., Ltd., Taber, Alta.

No. 44—Galt Colliery, Alberta Railway and Irrigation Co., Ltd., Lethbridge, Alta.

No. 47—Breckenridge and Lund Coal Co., Lundbreck, Alta.

*Frank-Blairmore Coal Field, Alta.*

No. 48—Seven Foot seam (No. 1 Byron), Leitch Collieries, Ltd., Passburg, Alta.

No. 32—Hillcrest Colliery, Hillcrest Coal and Coke Co., Ltd., Hillcrest, Alta.

No. 33—Bellevue Colliery, No. 1 seam, West Canadian Collieries Co., Ltd., Bellevue, Alta.

No. 28—Lille Colliery, No. 1 seam, West Canadian Collieries Co., Ltd., Lille, Alta.

No. 34—Denison Colliery, No. 2 seam, International Coal and Coke Co., Ltd., Coleman, Alta.

No. 34 SP.—Denison Colliery, No. 4 seam, International Coal and Coke Co., Ltd., Coleman, Alta.

*Crowsnest Coal Field, B.C.*

No. 31—No. 3 mine, Michel Colliery, Crowsnest Pass Coal Co., Ltd., Michel, B.C.

No. 30—No. 7 mine, Michel Colliery, Crowsnest Pass Coal Co., Ltd., Michel, B.C.

- No. 29—No. 8 mine, Michel Colliery, Crowsnest Pass Coal Co., Ltd., Michel, B.C.  
 No. 51—No. 2 seam south, Hosmer Mines, Ltd., Hosmer, B.C.  
 No. 52—No. 6 seam south, Hosmer Mines, Ltd., Hosmer, B.C.  
 No. 53—No. 8 seam south, Hosmer Mines, Ltd., Hosmer, B.C.  
 No. 27—No. 2 mine, Coal Creek, Crowsnest Pass Coal Co., Ltd., Fernie, B.C.  
 No. 26—No. 5 mine, Coal Creek, Crowsnest Pass Coal Co., Ltd., Fernie, B.C.

*Cascade Coal Field, Alta.*

- No. 25—No. 1 or Old mine, H. W. McNeil Co., Ltd., Canmore, Alta.  
 No. 23—Pea size, Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.  
 No. 23 SP.—Buckwheat size, Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.  
 No. 23 M.—Mixed, 23 and 23 SP., Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.  
 No. 24—Briquettes from Bankhead Colliery, Bankhead Mines, Ltd., Bankhead, Alta.

*Similkameen Coal Field, B.C.*

- No. Ex. 1—No. 1 opening, Granite Creek, B.C.  
 No. Ex. 2—No. 2 opening, Granite Creek, B.C.  
 No. Ex. 3—No. 4 opening, Granite Creek, B.C.

*Nicola Valley Coal Field, B.C.*

- No. 22—Jewel seam, No. 1 mine, Middlesboro Colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C.  
 No. 22 SP.—Rat Hole seam, No. 2 mine, Middlesboro Colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C.  
 No. 22 M.—Mixture of 22 and 22 SP., Middlesboro Colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C.

*Whitehorse Coal Field, Yukon Territory.*

- No. Ex. 31—Upper seam, Tantalus mine, White Pass and Yukon Railway Co., Ltd., Yukon.  
 No. Ex. 32—Middle seam, Tantalus mine, White Pass and Yukon Railway Co., Ltd., Yukon.  
 No. Ex. 33—Lower seam, Tantalus mine, White Pass and Yukon Railway Co., Ltd., Yukon.

*Nanaimo-Comox Coal Field, Vancouver Island, B.C.*

No. 20—Wellington seam, Wellington - Extension Colliery,  
Wellington Colliery Co., Ltd., Extension, B.C.

No. 18—Upper seam, No. 1 mine, Western Fuel Co., Ltd.,  
Nanaimo, B.C.

No. 17—Lower seam, No. 1 mine, Western Fuel Co., Ltd.,  
Nanaimo, B.C.

No. 21—Lower seam, No. 4 mine, Comox Colliery, Wellington  
Colliery Co., Ltd., Cumberland, B.C.

No. 21 SP.—Lower seam, No. 7 mine, Comox Colliery, Wellington  
Colliery Co., Ltd., Cumberland, B.C.

No. 21 M.—Mixture of Nos. 4 and 7 Mines, Comox Colliery,  
Wellington Colliery Co., Ltd., Cumberland, B.C.

*Alert Bay Coal Field, Vancouver Island, B.C.*

No. Ex. 34—Suquash mine, Pacific Coast Coal Co., Alert bay,  
Vancouver island, B.C.

APPENDIX IV

MANUFACTURE AND TESTING OF COKE

BY

EDGAR STANSFIELD and J. B. PORTER.



## APPENDIX IV.

# MANUFACTURE AND TESTING OF COKE.

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## DETAILED RECORDS OF COKING TESTS.

An account is given of the methods employed in the coking tests in Vol. I, pp. 213-219, and of the preliminary tests, made before the methods were decided upon, in Vol. I, pp. 219-222. The following are notes made during the course of the tests, and may be studied with advantage in connexion with the summary records of the tests which will be found in Vol. I, Tables XXIX-XLIV inclusive.

After a test box of coal had been coked, quenched, and dried, it was in every case opened and examined by the writer, with occasional help from the coke oven staff experts, and notes made as to the character of the coke and any special points observed. In the case of cokes made at Lille and Coleman, this examination was done at McGill; in all other cases it was done at the coke ovens—such notes are marked (a).

A typical sample of the coke was then taken, which was afterwards, at McGill, divided into four similar samples of about three or four pounds weight (required for different purposes). This work was done by three members of the staff, who made notes which are marked (b). One of the above four samples was placed in a tray, and the trays were arranged for inspection according to the geographical order of the source of the coal. These tray samples were then carefully examined and compared and notes made by Dr. J. B. Porter, assisted by E. Stansfield, or by E. Stansfield, assisted by W. B. Meldrum. These notes, which are marked (c), usually took the form of classifying the cokes according to the following scheme:—

A = good commercial coke—subdivided +A, A, -A.

B = poor commercial coke—subdivided +B, B, -B.

C = an agglomerate, not commercial coke—subdivided +C, C, -C.

D = non-agglomerating.

The first inspection had the great advantage that the whole quantity of coke produced was under inspection, and its behaviour whilst it was being broken up for removal from the box gave considerable insight into its character. The tests in the Sydney district lasted over a month, and the tests in the Crowsnest district were unavoidably delayed until over six months later, so that it was impossible to maintain a uniform standard of criticism—a fair coke among a number of poor cokes would inevitably be regarded more favourably than the same coke, had it been examined about the same time as a number of good ones.

TABLE I  
AVERAGES OF ANALYSES OF COKES FROM FRESH COALS

	Otto-Hoffman at Sydney				Bernard at Sydney Mines		Bernard at Lille		Beehive at Coleman	
	Sydney, N.S.	Pictou, N.S.	Springhill, N.S.	Similkameen, B.C.	Sydney, N.S.	Joggins, Chignecto, N.S.	Frank-Blairmore, Alta.	Crows-nest, B.C.	Frank-Blairmore, Alta.	Crows-nest, B.C.
1. Ovens in which cokes were made.....	5	4	3	2	4	1	6	6*	2	2
2. Coal field.....	87.5 1.5 11.0 2.9	86.4 0.6 13.0 1.3	92.1 1.5 6.4 0.7	..... ..... 20.9 .....	84.1 2.6 13.3 1.7	78.0 2.4 19.6 5.5	76.9 0.9 22.2 .....	83.4 0.9 15.7 .....	78.6 1.9 19.5 .....	86.3 1.3 12.4 .....
3. Number of samples included in average.....	47 70.8 63.8	48 75.3 71.7	40 71.6 67.0	41 ..... 67.7	48 ..... 64.3	48 ..... 61.6	48 76.9 73.8	48 77.3 75.2	74 78.5 73.6	74 78.0 75.0
Chemical analysis of dry coke										
4. Fixed carbon (FC).....%	0.91 1.90	1.01 1.94	0.88 1.81	1.03 1.78	0.92 1.76	0.86 1.80	1.24 1.90	1.09 1.88	1.20 1.90	1.10 1.87
5. Volatile matter (VM).....%	52.0	47.9	51.4	42.1	47.7	52.0	34.7	42.0	36.8	41.2
6. Ash.....%	0.81	0.98	0.97	0.81	0.77	0.89	0.68	0.88	0.74	0.94
7. Sulphur.....%	42.4 34.8	47.3 46.6	49.9 48.3	34.2 28.4	36.6 28.6	46.2 41.1	23.8 16.3	36.6 32.1	27.0 19.8	38.5 35.8
8. Duration of coking..... hours										
9. Yield of dry coke from dry coal.....%										
10. Theoretical yield (FC + ash of coals coked) %										
11. Apparent specific gravity.....										
12. Real specific gravity.....										
13. Percentage cell space or porosity (P).....%										
14. Relative crushing strength (S).....										
15. Physical value (P × S).....										
16. Physical value (P × S <sup>2</sup> ).....										

\* One very bad sample omitted.

The second inspection was of a smaller quantity of coke, but had this advantage that all the cokes made in each district were examined about the same time and the hardness, etc., of the coke could be noted when the pieces were broken with a hammer.

At the third inspection, a still smaller sample was available and this could not be broken up, but all the samples from both districts were spread out at once for inspection, and as from time to time trays under inspection were taken back and compared with those already judged, it was possible to maintain a very constant standard of classification.

Where the notes included comparisons between cokes produced from coals from different collieries it has been thought better to omit such comparisons.

#### AVERAGES OF ANALYSES OF COKES FROM FRESH COALS.

For purposes of ready comparison, etc., average values have been calculated for the chemical and physical properties of the different cokes, classified under the coal fields from which the coals came, and according to the ovens in which the cokes were made. In calculating these averages, only those cokes are considered which were made from coals that had been mined less than one month before they were coked; only one coal had been mined more than half a month. These averages are shown in Table I.

Line 3 of the table gives the number of samples included in each average analysis; it will be fairly obvious that it is not possible to consider the difference, for example, between the average coke from Sydney coals coked in Otto-Hoffman ovens, and the average coke from Sydney coals coked in Bernard ovens, as due simply to the difference of oven, since different coals were coked in the two places.

#### COKING TESTS MADE BY MR. T. C. DENIS IN THE OTTO-HOFFMAN OVENS AT SYDNEY, JUNE 20-22, 1908.

Metal drums were used for these tests about 18" long by 8½" diameter; all coked for 41 hours.

Coal Ex. I, No. 1 Opening, Granite Creek, B.C. 44 lbs. dry coal, coked dry.

(a) Non-coking.

Coal Ex. 201, No. 1 Opening, Granite Creek, washed coal. 44 lbs. dry coal, coked dry.

(a) Non-coking.

Coal Ex. 2, No. 2 Opening, Granite Creek. 44 lbs. dry coal, coked dry.

(a) Fair coke.

Coal Ex. 202, No. 2 Opening, Granite Creek, washed coal. 44 lbs. dry coal, coked dry.

(a) Excellent coke.

Coal Ex. 3, No. 4 Opening, Granite Creek. 44 lbs. dry coal, coked dry.

(a) Decidedly non-coking.

Coal Ex. 203, No. 4 Opening, Granite Creek, washed coal. 44 lbs. dry coal, coked dry.

(a) Decidedly non-coking.

Coal 22, Jewel seam, Middlesboro colliery, Nicola Valley Coal and Coke Co., Ltd., Coutlee, B.C. 44 lbs. dry coal, coked dry.

(a) Non-coking.

The above drums were divided between two ovens, in each of which was also coked a drum containing about 55 pounds of moist, washed, Dominion Coal Co.'s coal, as charged into the ovens. The comparisons between these cokes and samples of coke produced at the same time in the open oven are given in Vol. I, pp. 219-220.

COKING TESTS MADE IN BATTERY IX OF THE OTTO-HOFFMAN OVENS  
OF THE DOMINION IRON AND STEEL CO., AT SYDNEY, C.B.,  
DECEMBER 1908 AND JANUARY 1909.

Preliminary Tests—Age of Coal.

Three coals were chosen for this test; the boxes containing them were charged into Oven 18, Battery IX, on Dec. 22, 1908, the oven was pushed 41 hours later. The boxes came out in good condition, the lids had sunk 1 or 2 inches.

*Box 1*, fresh Phalen seam coal from Dominion Coal Co., washed, as charged into ovens at the time. Coke C 1.

Weight of moist coal,  $38\frac{1}{2}$  lbs.

(a) Coke was excellent, very little small coke at the top, regular fracture, some larger cells in the centre but no sponge.

(b) Good ring, minimum of breeze, if anything slightly stronger than the next sample, also on the whole slightly cleaner in appearance, although there was more sooty coke.

*Box 2*. Coal 38, about 6 months old, Phalen seam coal from Dominion Coal Co., No. 1 colliery. Coke C1/38.

Weight of dry coal,  $37\frac{1}{2}$  lbs; of moist coal, 43 lbs; water in coal as coked = 12.8 per cent.

(a) Coke was excellent, very little small coke on top. A good piece of this coke, when shown to an expert, in comparison with a good piece of the previous sample, was with some hesitation picked as being from the older coal. The fact that this coal was unwashed might almost account for any difference.

(b) Decidedly good hard coke.

*Box 3*, Coal 12, about  $17\frac{1}{2}$  month's old coal from the No. 3 pit of the Nova Scotia Steel & Coal Co. Coke C1/12.

Weight of dry coal,  $36\frac{1}{2}$  lbs.; of moist coal, 41 lbs.; water in coal as coked = 11 per cent.

(a) Coke was quite good at the bottom, although even here not so good as in boxes 1 and 2; at the top of the box there was a layer, 2" or 3" thick, of very poor coke in which some of the original pieces of coal could be seen. A good piece of this coke was immediately detected as inferior to the two previous samples.

(b) Fair coke, breaks up rather easily.

The choice of coals for this test was unavoidably unsatisfactory as no strictly comparable coals of different ages were available; the fresh coal was washed and the two older coals were not; moreover, it was learned later that coal 12 is not regarded as a very good coking coal, even when fresh. The above was fortunately of little moment, as the verdict arrived at—that the coking quality of coal, even when stored carefully in sacks, does deteriorate somewhat with age, although not as much as is sometimes supposed—was confirmed by later tests on comparable coals. It was, however, shown that different coals varied very much in their susceptibility to aging.

#### Preliminary Tests—Time of Coking.

Boxes were filled as uniformly as possible with moist washed coal such as was being charged into the ovens at the time. This was Phalen seam coal from the Dominion Coal Co., washed at the washery of the Dominion Iron & Steel Co.; it is afterwards referred to as D.I. & S. Co. coal. These boxes were charged into different ovens where they were coked for different lengths of time. The 41 hour coke and the two 48 hour cokes were tests made primarily for other purposes, but as they are strictly comparable with the rest, they are included to complete the series. Battery X was off for repairs at this time, which was said to reduce the draught and heat of Battery IX. Battery X went into commission again about the New Year.

*30 Hour coke, C 11.* Charged into oven, Dec. 28, 1908.

Weight of moist coal, 43 lbs.

This sample was the result of an attempt to make 24 hour coke. The box was charged into an oven, into which less coal than usual was subsequently introduced, but even so it was not found possible to push the oven after 24 hours, as a large quantity of volatile matter was still left in the coal. The doors were left loose and the oven pushed six hours later. Air could get in past the doors in the last period, and the resulting combustion of the coke would probably produce an unusually hot oven.

(a) Normal good coke in appearance.

*36 Hour Coke, C 12.* Charged into oven, Dec. 26.

Weight of moist coal, 45 lbs.

(a) Normal good coke in appearance.

*41 Hour Coke, C<sup>1</sup> 1.* Charged into oven, Dec. 22.

Weight of moist coal,  $38\frac{1}{2}$  lbs.

(a) Coke was excellent, very little small coke at the top, regular fracture, some larger cells in the centre but no sponge.

*48 Hour Coke, C 5.* Charged into oven, Dec. 23.

Weight of moist coal,  $41\frac{1}{2}$  lbs.

(a) Good coke with very little small.

*48 Hour Coke, C 7.* Charged into oven, Dec. 24.

Weight of moist coal,  $43\frac{1}{2}$  lbs.

(a) Quite good coke.

*60 Hour Coke, C 13.* Charged into oven, Dec. 29.

Weight of moist coal, 43 lbs.

(a) Good, silvery grey coke, probably better than ordinary, but hardly as good as the 72 hour coke.

*72 Hour Coke, C 14.* Charged into oven, Dec. 23.

Weight of moist coke,  $44\frac{1}{2}$  lbs.

(a) Excellent silvery grey coke, the best coke produced in tests made up to this time.

In general, (a) the cokes were good from all the tests but improved with the time. The 72 hour coke was the best produced up to then, and the 60 hour not much worse.

(b) Samples C11-C14 classified by ring and appearance were placed in the correct order; classified by sound alone, C12 was placed too high. The longer time of coking brightens and hardens the coke.

#### Preliminary Tests—Position in Oven.

Four boxes were filled as usual with D.I. & S. Co. coal; three of these were fastened to three platforms of a rough lumber frame, which was then pushed into an empty oven, and the fourth box pushed along the floor of the oven to the foot of the frame. In this way one box was resting on the floor of the oven, the others being supported on successive steps of 1'-4" in height. There was an unexpected delay of nearly five minutes in charging coal into the oven, during which time the frame burned fiercely. The latter, however, held the boxes up until they were supported by the coal charged into the oven, as the boxes still maintained their original relative positions when the coke was pushed, although they had sunk with the contraction of the charge during coking. The boxes were charged into the oven on Dec. 24, and coked for forty-eight hours.

*Box on floor of oven. Coke C7.*

Weight of moist coal,  $43\frac{1}{2}$  lbs. Yield of dry coke from dry coal = 70.6%.

*Box supported 1'-4" above floor. Coke C8.*

Weight of moist coal,  $43\frac{1}{2}$  lbs. Yield of dry coke from dry coal = 70.4%.

*Box supported 2'-8" above floor. Coke C9.*

Weight of moist coal,  $42\frac{1}{2}$  lbs. Yield of dry coke from dry coal = 70.8%.

*Box supported 4'-0" above floor. Coke C10.*

Weight of moist coal,  $43\frac{1}{2}$  lbs. Yield of dry coke from dry coal = 70.2%. This top box was not entirely protected by coal, one of the top corners of the box being burned away. The coke did not appear to be burned.

(a) The coke in all four boxes was quite good, but samples C7 and C8 were perceptibly better than C9 and C10. There was hardly any perceptible difference between C7 and C8, one piece of C7 looking better than a piece of C8, and vice versa with other pieces. C9 was perhaps a trace better than C10, but not very noticeably so; The average of C7 and C8 was, however, noticeably better than the average of C9 and C10. The coke in the two lower boxes was firmer and harder than in the two upper ones; in the lower boxes there were also less open structure and less breeze.

(b) Previous opinion confirmed.

#### Preliminary Tests—Compression of Coal.

Two boxes  $18'' \times 16'' \times 10''$  were filled with D.I. & S. Co. coal; the first box was filled with as little compression of the coal as possible; the second box was filled, little by little, each layer being pressed well down before more coal was added. In each case the lid was rivetted in position so that it could not come out or get pressed farther in. The boxes were charged on Dec. 28, and coked for 48 hours.

*Uncompressed Coal, Coke C15.*

Weight of moist coal,  $74\frac{1}{2}$  lbs.

(a) Normal good coke.

*Compressed Coal, Coke C16.*

Weight of moist coal,  $96\frac{1}{2}$  lbs. This box was filled about  $\frac{3}{4}''$  to  $1''$  fuller than the previous box.

(a) Normal good coke, but somewhat denser than usual. There was very little difference between the samples except that the compressed coal produced the denser coke.

(b) Coke C16 denser and brighter than C15.

#### Preliminary Tests—Moisture in Coal.

Three boxes were filled with D.I. & S. Co. coal, one dry, one ordinarily damp, and the third very wet; these were charged into an oven on Dec. 23, and coked for 48 hours.

*Dry Coal, Coke C4.*

Weight of moist coal,  $47\frac{1}{2}$  lbs; weight after drying,  $42\frac{1}{2}$  lbs.; moisture in original moist coal, 10.5-per cent.

Moist coal was taken as usual and weighed in a box; the coal was then divided among 4 boxes and dried on an electric oven over night, and inside

it for about six hours the next day; the oven was supposed to keep at 110°C. The coal was then brought back to its original box and reweighed; a little dust would be lost and the coal was probably not absolutely dry.

(a) Good coke; but there was a good deal more small coke on the top of the box than was the case with the ordinary wet coal. The quality of coke at the bottom was not apparently different.

*Ordinary wet coal, Coke C5.*

Weight of moist coal, 41½ lbs. Probably about 10 per cent water.

(a) Good coke with very little small.

*Very wet coal, Coke C6.*

Weight of wet coal, 54 lbs.

This coal was taken from the top of one of the washery draining tanks just under a spout; it was rather smaller coal than usual, and as it was not very wet, water was poured into the box during the filling process and the coal stirred with a stick. The box was left to drain for half an hour before weighing. The result of the thorough wetting of the fine coal was that the coal settled down more compactly than usual into the box.

(a) The coke was more friable on the top and in the centre than C5, but not so much so as C4; the best coke in C6 was hardly as good as the best coke in C5. (Mr. Lucas preferred C6 to C5, presumably on account of its greater density).

(b) There is very little choice between C4, C5, and C6. C4 is the hardest and gives the best ring when hit; C5 contains more soot than C4, also it is not quite so strong; it is the dirtiest and yet the brightest in spots. C6 is very close to C5.

**Preliminary Tests—Yield of Coke.**

In order to compare the yields of coke obtained in box tests with those obtained in commercial practice, a sample of D.I. & S. Co. coal was dried for three days on an oil-cloth on a cool part of the boiler flue, weighed, moistened, put in a box, and coked in the usual way for 48 hours. Charged about January 7.

Weight of dry coal, 42 lbs.; water in coal as coked 7.9%; yield of dry coke from dry coal, 72.3%.

(a) Box came out in good condition; the coke was practically as usual, but possibly a trace more slaty matter visible.

Careful tests made some years before on a single oven showed 67% commercial coke and 2% breeze produced from dry, washed coal; this practice had been gradually improved until at the time the above test was made the yield was about 70% commercial coke and 1.5% breeze, or 71.5% in all, as compared with 72.3% in the box test.

### Preliminary Tests—Comparison of Open Oven with Box Coke.

A sample of coke, C83, produced from D.I. & S. Co. coal in the usual way in an Otto-Hoffman oven, was taken to represent the average output of an oven.

(b) Compared this coke with C1, which is the same coal coked for the same time, 41 hours, in a box. More soot than in C1, but no more than in some other similar cokes; apparently less dense.

(c) Open oven coke is a trifle duller and more porous on the average than box coke; this impression is possibly due to extra density of inch of skin next to the box.

### Blending Tests.

A few blending tests were added to the regular coking tests in order to ascertain the possibility of converting anthracite or lignite screenings into a merchantable product, by means of coking, after blending with a good coking coal.

#### *1 part coal 23M with 2 parts D.I. & S. Co. coal.*

Coal 23M was an anthracite coal from the Bankhead Colliery, Alta.

16 lbs. of 23M and 35 lbs. of moist D.I. & S. Co. coal were mixed well together and moistened on an oil-cloth, then pressed down into a box and coked for 48 hours.

(a) A fair commercial coke; the larger particles of anthracite still show; by using anthracite *dust*, very well mixed in, it should make a useful coke.

(b) Breaks up rather easily, producing breeze.

(c) Class B.

#### *1 part coal 23M with 2 parts coal 31.*

Coal 31 was from the No. 3 mine, Michel colliery, B.C.

16 lbs. of 23M and 32 lbs. of 31 were mixed, damped, boxed, and coked, as before.

(a) A fair coke cementing together particles of unchanged anthracite.

(b) Produces a good deal of breeze, no regular fracture.

(c) Class—B.

#### *2 parts coal 23M with 3 parts coal 26.*

Coal 26 was from No. 5 mine, Coal Creek, Fernie, B.C.

20 lbs. of 23M, crushed to pass a wire screen of 4 mesh to the inch, and 30 lbs. of 26 were treated as before.

(a) Coal coked to a dry crumbly mass showing particles of original anthracite; probably of no commercial value.

(b) Soft and friable, producing a lot of breeze.

(c) Class + C.

*1 part coal 25 with 2 parts coal 20.*

Coal 25 was an anthracitic coal from the Old mine, Canmore, Alta., coal 20 was from the Wellington seam, Wellington-Extension Colliery, Vancouver island.

Took 16 lbs. of 25 and 32 lbs. of 20 and treated as before.

- (a) Hardly a commercial coke; had only just coked and there was a lot of loose breeze, a lot of the particles not having fused at all.
- (b) Friable coke, no regular cleavage.
- (c) Class — B.

*1 part coal 2040 with 2 parts coal 31.*

Coal 2040 was a lignite from Taylorton, Sask., and coal 31 was from Michel, B.C.

Took 16 lbs. of 2040 and 32 lbs. of 31 and treated as before.

- (a) Coke might possibly be of some commercial use; the particles of lignite were all there unchanged, but cemented into the body of the coke.
- (b) Soft, friable, dull looking coke.
- (c) Class — B.

**Coking Tests of Regular Coals.**

*Coal 50.*—North Atlantic Collieries, Port Morien, N.S., Gowrie seam. Coke C1/50. Age of coal when coked less than  $\frac{1}{2}$  month.

Dry coal coked, 49 $\frac{3}{8}$  lbs. Water as coked, 8.4%. Charged to oven, Jan. 17, 1909. Coked 40 hours.

(a) The coke was insufficiently quenched and showed signs of burning. Sound coke to top, on the whole fairly good quality, although breaking up rather easily. Washing the coal would make a great improvement.

(b) Open cellular coke; breaks up easily but without producing much breeze.

(c) Class — A.

*Coal 36.*—Dominion Coal Co., Glace Bay, N.S., Dominion No. 7, Hub seam.

Coke C1/36. Age of coal, under 7 months.

Dry coal coked, 48 lbs. Water in coal as coked, 9.7%. Charged to oven, Jan. 14. Coked 48 hours.

(a) Box came out of oven in poor condition. Coke looks like coke from similar fresh coal, coke C1/2036, the only visible difference being that the coke from the older coal was more fragile and broke up into smaller pieces when it was taken out of the box.

(b) Very pretty, but not very strong coke; breaks into curved rods.

(c) Class + A. More fissured than coke from fresh coal.

*Coal 2036.*—Fresh sample of coal like 36.

Coke C1/2036. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 47 $\frac{1}{2}$  lbs. Water in coal as coked, 11.0%. Coked with C1/36.

(a) Coke shows fair shrinkage, good quality to top; is nice clean and bright, but like other cokes from D.C. Co.'s coals has a good deal of cross fracture, although this is, if anything, more conspicuous than usual with this coal.

(b) Slightly brighter and stronger than C1/36, and does not break up into quite such small pieces.

(c) Class + A.

*Coal 35.*—Harbour seam, Dominion No. 9.

Coke C1/35. Age of coal, under 7 months.

Dry coal coked, 49 lbs. Water in coal as coked, 7.8%. Box charged to oven Jan. 14. Coked 48 hours.

(a) Box came out in bad condition and some coke was lost. Coke like that from similar fresh coal, C1/2035, only slightly less cellular; sound to top with regular cleavage but breaks up rather easily, owing to cross fractures.

(b) Good hard coke.

(c) Class A.

*Coal 2035.*—Fresh sample of coal like 35.

Coke C1/2035. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 48 lbs. Water as coked, 10.3%.

Coked with C1/35.

(a) The coke was fairly tight in the box. Good coke, open cell structure, sound to top, regular cleavage, but rather smoky.

(b) Not noticeably different from C1/35.

(c) Class A. Rather brighter and better than C1/35.

*Coal 35 SP.* Phalen seam, Dominion No. 5.

Coke C1/35 SP. Age of coal, under 7 months.

Dry coal coked, 47 lbs. Water as coked, 7.6 per cent. Charged Jan. 14, and coked for 48 hours.

(a) Good sound coke to top of box. Ordinary good coke in appearance, regular cleavage, but cross fractures cause the coke to break up somewhat.

(b) Good strong coke.

(c) Class A. Slightly inferior to C1/35.

*Coal 2035 SP.* Fresh sample of coal like 35 SP.

Coke C1/2035 SP. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 47 lbs. Water as coked, 10.6%. Coked with C1/35 SP.

(a) Good sound coke to top of box. Coke had regular cleavage, etc., like cokes C1/35 and C1/2035.

(b) Not noticeably different from the coke from the older coal C1/35 SP.

(c) Class A. Very little difference between the cokes from the fresh and old coals, both slightly inferior to C 1/35.

*Coal 38.* Phalen seam, Dominion No. 1.

Coke C1/38. Age of coal, under 7 months.

Dry coal coked, 49 lbs. Water as coked 8.5%. Charged Jan. 17, and coked for 40 hours.

(a) Good strong coke, sound to top of box, regular cleavage, breaks up into curved rods. Rather smoky but otherwise looks very nice.

(b) Decidedly strong coke; better than cokes made from same or similar fresh coal in the Bernard ovens at Sydney Mines, cokes, C3/38, and C3/2038.

(c) Class + A. Better than coke C 3/38.

*Coal 37.* Emery seam, Dominion No. 10.

Coke C1/37. Age of coal, under 7 months.

Dry coal coked, 48½ lbs. Water as coked, 6.0%. Charged Jan. 14, and coked for 48 hours.

(a) Box came out in poor condition. Very fair coke, possibly a trace dirtier and more fragile than coke from similar fresh coal, but the difference was too slight to be convincing.

(b) Not very strong coke, contains a good deal of soot and visible slate.

(c) Class + B.

*Coal 2037.* Fresh sample of coal like 37.

Coke C1/2037. Age of coal, under ½ month.

Dry coal coked, 46½ lbs. Water as coked, 11.3%. Coked with C1/37.

(a) Very fair coke. Not so pretty looking as coke C1/36, but does not break up so small.

(b) Harder and less fragile than coke C1/37 and also shows less sooty matter.

(c) Class - A.

*Coal 39.* Lingan seam, Dominion No. 12.

Coke C1/39. Age of coal, under 7 months.

Dry coal coked, 47½ lbs. Water as coked, 10.6%. Charged Jan. 17, and coked for 40 hours.

(a) A good strong coke, sound to top, very much like C1/38; regular cleavage, markedly curved; a little smoked, but nice looking coke.

(b) Bright, hard coke, but breaks up rather easily.

(c) Class A. Better coke than that from same coal coked in Bernard oven.

*Coal 12.* Nova Scotia Steel and Coal Co., Sydney Mines, N.S. No. 3 colliery.

Coke C1/12. Age of coal, under  $17\frac{1}{2}$  months.

Dry coal coked,  $36\frac{1}{2}$  lbs. Water as coked, 11.0%. Charged Dec. 22, and coked for 41 hours.

(a) Coke was quite good at the bottom, but at the top of the box there was a layer 2" or 3" thick of very poor coke in which some of the original pieces of coal could be seen.

(b) Fair coke, breaks up rather easily.

(c) Class + B. Better coke than that from same coal coked in Bernard oven, C3/12.

*Coal 14.* Inverness Railway & Coal Co., Inverness colliery, N. S.

Coke C1/14. Age of coal, under  $16\frac{1}{2}$  months.

Dry coal coked,  $50\frac{1}{2}$  lbs. Water as coked, 8.0%. Charged Jan. 4, and coked for 48 hours.

(a) Box was broken and half the contents lost. Had not coked although a little had caked.

*Coal 15.* Richmond Ry. Coal Co., Port Hood colliery, N. S.

Coke C1/15. Age of coal, under  $16\frac{1}{2}$  months.

Dry coal coked,  $47\frac{1}{2}$  lbs. Water as coked, 8.4%. Charged Jan. 4, and coked for 48 hours.

(a) Not commercial coke; a lot of loose material at the top, the rest caked with a suspicion of coking close to the sides and bottom; sulphur visible at top.

(b) Friable agglomerate, showing a coking tendency at the outside.

(c) Class + C.

*Coal 2004.* Acadia Coal Co., Stellarton, N. S. A second sample from the Six Foot seam, Vale colliery.

Coke C1/2004. Age of coal, under  $16\frac{1}{2}$  months.

Dry coal coked,  $49\frac{1}{2}$  lbs. Water as coked, 8.6%. Charged Jan. 3, and coked for 48 hours.

(a) Not commercial coke. Top layer loose, below that caked, but not more than 1" or 2" really coked.

(b) Friable agglomerate, showing a coking tendency at the outside.

(c) Class + C. No good.

*Coal 16.* Foord seam, Allan Shaft colliery.

Coke C1/16. Age of coal, under  $16\frac{1}{2}$  months.

Dry coal coked, 47 lbs. Water as coked 10.2%. Charged Jan. 10, and coked for 48 hours.

(a) Excellent coke, sound to top of box; hardly so strikingly good as that from the fresh similar coal, C 1/2016; not so much shrinkage and harder to remove from the box.

(b) Good, hard, strong coke.

(c) Class A. Good, strong coke, but still showing some original grains.

*Coal 2016.* Fresh sample of coal like 16.

Coke C1/2016. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 44 $\frac{1}{2}$  lbs. Water as coked, 6.6%. Coked with C1/16.

(a) A very excellent coke, sound to the top of the box; some shrinkage, resulting in very regular cleavage.

(b) Excellent coke, slightly brighter and harder than C 1/16.

(c) Class + A. An exceptionally good coke.

*Coal 1.* Third seam, Albion colliery.

Coke C1/1. Age of coal, under 21 months.

Dry coal coked, 49 lbs. Water as coked, 8.2%. Charged Jan. 3, and coked for 48 hours.

(a) Not a commercial coke. A lot of loose coal on the top, and the rest more caked than coked.

(b) Soft, friable agglomerate, not really bonded.

(c) Class C. Merely agglomerate, no commercial value.

*Coal 2.* Cage Pit seam, Albion colliery.

Coke C1/2. Age of coal, under 21 months.

Dry coal coked, 46 lbs. Water as coked, 7.8%. Charged Jan. 10, and coked for 48 hours.

(a) Box came out badly damaged. Coal had caked for about 3" round sides and bottom, the rest was quite loose.

(b) Dirty agglomerate, no true coke.

(c) Class C. Merely agglomerate, no commercial value.

*Coal 2002.* Fresh sample of coal like 2.

Coke C1/2002. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 46 lbs. Water as coked, 8.2%. Coked with C1/2.

(a) Coke sound to top of box, not much shrinkage; coke slightly burned owing to insufficient quenching. A good commercial coke fit for any blast furnace.

(b) Good, hard, dense coke, regular fracture; shows no resemblance to the coke from the old coal from same seam, C1/2.

(c) Class—A. Good, strong, silvery coke; still, however, showing original fragments on outside.

*Coal 8.* Main seam, Acadia colliery.

Coke C1/8. Age of coal, under 21 months.

Dry coal coked, 48 $\frac{1}{2}$  lbs. Water as coked, 8.0%. Charged Jan. 10, and coked for 48 hours.

(a) Box came out damaged but no coke lost. Coke firm to top, very little shrinkage; a good hard coke fit for anything.

(b) Good, hard, strong coke, very little inferior to coke from similar fresh coal except in lustre.

(c) Class — A. Good, strong coke.

*Coal 2008.* Fresh sample of coal like 8.

Coke C1/2008. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked,  $47\frac{1}{2}$  lbs. Water as coked, 6.7%. Coked with C1/8.

(a) Box came out slightly damaged, probably no coke lost. Little shrinkage; rather more loose at the top than usual, otherwise a good hard coke fit for anything.

(b) Dense, hard coke; first class quality.

(c) Class A. Slightly brighter and denser than coke C1/8.

*Coal 3.* Intercolonial Coal Co., Westville, N.S., Main seam, Drummond colliery.

Coke C1/3. Age of coal, under 21 months.

Dry coal coked,  $48\frac{1}{2}$  lbs. Water as coked, 7.0%. Charged Jan. 10, and coked for 48 hours.

(a) Box slightly damaged, no coke lost. Coke slightly burned, little shrinkage; a good, strong, commercial coke, sound to the top of the box, and little, if any, inferior to coke from similar fresh coal, coke C1/2003.

(b) Dense, hard coke; not very regular fracture.

(c) Class — A. Good, strong coke, slightly dull.

*Coal 2003.* Fresh coal, similar to coal 3.

Coke C1/2003. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 47 lbs. Water as coked, 7.0%. Coked with C1/3.

(a) Box badly damaged, but coke sound inside, although slightly burned. Little shrinkage; a good, strong, commercial coke, sound to top of box.

(b) Similar to coke C1/3, but harder and much stronger; a particularly hard coke to break.

(c) Class A. Slightly brighter than coke C1/3, but very little if any better.

*Coal 49.* Cumberland Ry. & Coal Co., Springhill, N.S., No. 1 Colliery.

Coke C1/49. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked,  $46\frac{1}{2}$  lbs. Water as coked, 8.8%. Charged Jan. 17, and coked for 40 hours.

(a) Sound coke to top of box; regular cleavage but breaks up readily into long, thin, curved rods; a first class coke with a very metallic ring.

(b) Good, hard coke; very regular fracture, breaks up into small pieces but no breeze.

(c) Class A. Strong, compact, and good looking; prisms rather small, this is characteristic of all the Springfield cokes.

*Coal 5.* Springhill No. 2 colliery.

Coke C1/5. Age of coal, under  $21\frac{1}{2}$  months.

Dry coal coked, 49 lbs. Water as coked, 7.6%. Charged Jan. 17, and coked for 40 hours.

(a) Badly quenched, burned in centre at top. A good commercial coke, but shows distinct signs at the top of approaching a non-coking condition owing to age.

(b) Medium good coke, not very strong.

(c) Class + B. Good looking, but much fissured prismatically.

*Coal 2005.* Fresh sample of coal like 5.

Coke C1/2005. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 46 lbs. Water as coked, 9.6%. Coked with C1/5.

(a) A good coke, sound to top and showing no lack of fusion like coke C1/5 did; regular, slightly curved cleavage.

(b) Medium coke, fairly strong, breaks into curved rods.

(c) Class - A. Slightly better than coke C1/5, but has the same characteristics.

*Coal 6.* Springhill No. 3 colliery.

Coke C1/6. Age of coal, under  $21\frac{1}{2}$  months.

Dry coal coked,  $49\frac{1}{2}$  lbs. Water as coked, 8.6%. Charged Jan. 17, and coked for 40 hours.

(a) Coke a trace burned at bottom. Coke almost exactly like C1/5; a fair coke but with signs of lack of fusion at top.

(b) Fair coke, but not very strong.

(c) Class + B; a trace better than C1/5.

*Coal 2006.* Fresh sample of coal like 6.

Coke C1/2006. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 47 lbs. Water as coked, 10.3%. Coked with C1/6.

(a) Coke a trace burned, but general appearance unspoiled; an excellent coke, sound to top, similar to C1/2005; regular, slightly curved cleavage.

(b) Harder and better coke than C1/6; breaks up more into curved regular rods.

(c) Class A. Distinctly better than coke C1/6.

*Coal 7.* Maritime Coal, Ry., and Power Co., Chignecto colliery, N.S.

Coke C1/7. Age of coal, under 21 months.

Dry coal coked,  $45\frac{1}{2}$  lbs. Water as coked, 7.6%. Charged Jan. 3, and coked for 48 hours.

(a) Box had hole at end, possibly a little lost. Fair coke at bottom, not very strong, but fairly good, silvery fracture; at the top there was some uncaked coal. New coal might possibly give much better coke.

(b) Very irregular coke, in parts reasonably hard, in other parts very friable.

(c) Class + B.

*Coal 9.* Minudie Coal Co., River Hebert, N.S., Minudie colliery.

Coke C1/9. Age of coal, under 21 months.

Dry coal coked, 51 lbs. Water as coked, 7.5%. Charged Jan. 4, and coked for 48 hours.

(a) Box badly damaged, some coke lost, hardly enough quenched. Not commercial coke, a lot of loose matter with a slight coking tendency towards the bottom. Some visible sulphur.

(b) Soft and friable, had scarcely coked.

(c) Class - B.

*Coal 43.* Canada West Coal Co., Taber, Alta., Canada West Colliery.

Coke C1/43. Age of coal, under 5½ months. Charged Jan. 4, and coked for 48 hours.

(a) Box badly damaged and most of contents lost. There were some lumps of coked pitch left, but otherwise coal looked unaltered, being still quite shiny in parts.

N.B.—There was no possibility of the above coal coking, but it was hoped to get a determination of loss on coking to compare with the volatile matter as determined in the laboratory; it was, however, not thought worth repeating after the above failure.

*Coal 48.* Leitch collieries, Passburg, Alta. Seven Foot seam or No. 1 Byron.

Coke C1/48. Age of coal, under 5½ months. Dry coal coked, 48½ lbs. Water as coked, 6.9%. Charged Jan. 4, and coked for 48 hours.

(a) Little or no shrinkage; good sound coke from top to bottom.

(b) Bright looking, fair coke, open cellular structure, not very strong but does not produce much breeze.

(c) Class + B.

*Coal 32.* Hillcrest Coal & Coke Co., Hillcrest colliery, Alta.

Coke C1/32. Age of coal, under 8 months.

Dry coal coked, 46½ lbs. Water as coked, 7.8%. Charged Jan. 2, and coked for 48 hours.

(a) Box damaged at bottom, probably very little coke lost. Little, if any shrinkage, coke not firm to the top. The coke itself was excellent in colour, hard and porous, but there were a lot of particles

of unchanged material; possibly a higher temperature might have given a very good coke.

- (b) Bright, good looking coke, but very friable.
- (c) Class + B.

*Coal 33.* West Canadian collieries, No. 1 seam, Bellevue colliery, Alta.  
Coke C1/33. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 47 lbs. Water as coked, 6.7%. Charged Jan. 2, and coked for 48 hours.

(a) Box badly damaged, coke a little burned in one place. Little if any shrinkage; had coked hard to top, regular cleavage; a fair commercial coke, but not enough fusion.

- (b) Good, strong, tough coke; better than C1/28.
- (c) Class + B.

*Coal 28.* West Canadian collieries, No. 1 seam, Lille colliery, Alta.  
Coke C1/28. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked,  $46\frac{1}{2}$  lbs. Water as coked, 9.7%. Charged Jan. 2, and coked for 48 hours.

(a) Coal was very wet, but, like most coals, it appeared to occupy greater volume after damping than before. Box came out in poor condition, probably little lost. Shrinks a little in coking; fair coke, hard, but in spots unfused bits of coal. There was some good open cell structure at the top.

- (b) Friable coke with a good deal of breeze.
- (c) Class B.

*Coal 34.* International Coal & Coke Co., Coleman, Alta., No. 2 seam, Denison colliery.

Coke C1/34. Age of coal, under 8 months.

Dry coal coked,  $47\frac{1}{2}$  lbs. Water as coked, 6.4%. Charged Jan. 2, and coked for 48 hours.

(a) Coke burned in one small spot. Little or no shrinkage, difficult to remove from box; coke is dense but crumbles when hit hard. In the top of the box, especially, there was a lot of coal which had sintered together but had not fused to form coke. Probably would be of commercial value for copper smelting.

(b) Medium hard coke, breaks up rather easily but without producing much breeze. Contains "white mould" (certain cokes contained patches of soft, white, fibrous matter, which resembled mould in appearance).

- (c) Class B.

*Coal 34 SP.* No. 4 seam, Denison colliery.

Coke C1/34 SP. Age of coal, under 8 months.

Dry coal coked, 48 lbs. Water as coked, 7.0%. Charged Jan. 3, and coked for 48 hours.

(a) Slight shrinkage; good coke with marked cleavage; some particles unchanged, probably largely slaty; contains "white mould".

(b) Fairly hard coke, but cleavage not very regular.

(c) Class + B.

*Coal 31.* Crowsnest Pass Coal Co., No. 3 mine. Michel colliery, B.C.  
Coke C1/31. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 48 lbs. Water as coked, 8.6%. Charged Jan. 2, and coked for 48 hours.

(a) The coal was fine and heavy. Not much shrinkage; excellent coke up to top of box.

(b) Dense, hard coke, but breaks up easily.

(c) Class + B.

*Coal 30.* No. 7 mine, Michel colliery, B.C.

Coke C1/30. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 46 lbs. Water as coked, 8.9%. Charged Jan. 2, and coked for 48 hours.

(a) Box rather damaged. Irregular cleavage; not commercial coke, had caked almost to top, but even in best coke at the bottom the shape of some of the original pieces could be seen.

(b) Very friable coke, not properly bonded; no regular cleavage.

(c) Class - B.

*Coal 29.* No. 8 mine, Michel colliery, B.C.

Coke C1/29. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked,  $50\frac{1}{2}$  lbs. Water as coked, 11.2%. Charged Jan. 2, and coked for 48 hours.

(a) Very hard, and as there was little or no shrinkage, hard to get out of box; cleavage not very regular; a fair coke on the whole; like the Fernie cokes, but if anything less actual fusion, some pieces showing unchanged at the top.

(b) Moderately good.

(c) Class + B.

*Coal 27.* Crowsnest Pass Coal Co., No. 2 mine, Coal Creek, Fernie, B.C.

Coke C1/27. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 47 lbs. Water as coked, 9.6%. Charged Jan. 1, and coked for 48 hours.

(a) Very little shrinkage; sound coke to centre and top; a good coke, very like C1/26.

(b) Strong under hammer.

(c) Class + B.

*Coal 26.* No. 5 mine, Coal Creek, B.C.

Coke C1/26. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked,  $48\frac{1}{2}$  lbs. Water as coked, 7.0%. Charged Jan. 1, and coked for 48 hours.

(a) A little spoiled by incomplete quenching. Very little shrinkage, a sound coke to centre and top; a good, hard coke.

(b) Not notably strong, but makes very little breeze in handling. More silvery in appearance than the average coke.

(c) Class + B.

*Coal 25.* H. W. McNeil Co., No. 1 mine, Canmore, Alta.

Coke C1/25. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 47 lbs. Water as coked, 7.4%. Charged Jan. 1, and coked for 48 hours.

(a) Box was in good condition, probably very little spilt. The coal was very little changed; there were a few traces of sintering.

(c) Class D.

This test was made to determine yield to compare with chemical analysis. Loss on coking = 18.4% of dry coal. Volatile matter from laboratory analysis = 17.2% of dry coal.

*Coal 23 M.* Bankhead Mines, Ltd., Bankhead colliery, Alta.

Coal C1/23 M. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked,  $46\frac{1}{2}$  lbs. Water as coked, 6.5%. Charged Dec. 31, and coked for 48 hours.

(a) The lid had sunk about 2" but the coal had hardly changed at all in appearance.

(c) Class D.

This test was made to determine yield to compare with chemical analysis. Loss on coking = 12.1% of dry coal. Volatile matter from laboratory analysis 12.6% of dry coal. The warping of the iron boxes with the heat makes it difficult to ensure no loss when taking out of oven, when the contents are not caked.

*Coal 22 SP.* Nicola Valley Coal and Coke Co., Coutlee, B.C.

Rat Hole seam, No. 2 mine, Middlesboro colliery.

Coke C1/22 SP. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 46 lbs. Water as coked, 7.1%. Charged Dec. 31, and coked for 48 hours.

(a) Box was badly damaged. There was a trace of caking through the bottom 3" or 4"; the top was quite loose.

(c) Class + C.

*Coal 22 M.* Coal from Mines 1 and 2, Middlesboro colliery, B.C.

Coke C1/22 M. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 45 lbs. Water as coked, 6.0%. Charged Dec. 31, and coked for 48 hours.

(a) Had not coked at all, bottom 2" or 3" had loosely caked. (Sample kept was of caked part.)

(c) Class C.

*Coal 20.* Wellington Colliery Co., Wellington seam, Extension colliery, B.C.

Coke C1/20. Age of coal, under 9 months.

Dry coal coked, 43½ lbs. Water as coked, 8.7%. Charged Dec. 30, and coked for 48 hours.

(a) Shrinks on coking; medium good coke, breaks rather easily; good silvery cell structure in parts but more generally dirty; probably would do for iron blast furnace.

(c) Class — A.

*Coal 18.* Western Fuel Co., Nanaimo, B.C., Upper seam, No. 1 mine.

Coke C1/18. Age of coal, under 9 months.

Dry coal coked, 43½ lbs. Water as coked, 8.5%. Charged Dec. 30, and coked for 48 hours.

(a) Caked towards bottom of box, but loose at the top; not commercial coke.

(c) Class C.

*Coal 17.* Lower seam, No. 1 mine, Nanaimo, B.C.

Coke C1/17. Age of coal, under 9 months.

Dry coal coked, 45½ lbs. Water as coked, 9.7%. Charged Dec. 30, and coked for 48 hours.

(a) No real coke, though a little had caked for 3" at the bottom; non-coking coal.

(c) Class C.

*Coal 21.* Wellington Colliery Co., Cumberland, B.C. Lower seam, No. 4 mine, Comox colliery.

Coke C1/21. Age of coal, under 8½ months.

Dry coal coked, 44½ lbs. Water as coked, 6.3%. Charged Dec. 30, and coked for 48 hours.

(a) Shrinks on coking. Hard and dense and not much broken up, but not very good looking coke. The centre and top were more caked than coke and the whole could only be described as poor coke; on the border line of coking; might give good coke at a higher temperature, or with fresher coal.

(c) Class — A.

*Coal 21 M.* Mixture of coal from Lower seam, Mines 4 and 7, Comox colliery.

Coke C1/21 M. Age of coal under 8½ months.

Dry coal coked, 46 lbs. Water as coked, 8.5%. Charged Dec. 30, and coked for 48 hours.

(a) Coke very like C1/21, only distinctly better; more had really coked and less only caked.

(b) Very irregular; some strong.

(c) Class—A. Better than C1/21.

*Coal Ex. 31.* White Pass & Yukon Ry. Co., Whitehorse, Yukon, Upper seam, Tantalus mine.

Coke C1/Ex. 31. Age of coal, under 7 months.

Dry coal coked, 95½ lbs. (Large boxes were used for four Yukon coals). Water as coked, 9.9%. Charged Jan. 6, and coked for 48 hours.

(a) Not a commercial coke; coked or caked throughout, but coke a dirty grey colour; heavy and crumbly, like dried mortar in appearance.

(b) Dense friable material, very little regular fracture. Contains "white mould;" this was composed of hexagonal or tetragonal needle-like crystals.

(c) Class + C.

*Coal Ex. 231.* Coal Ex. 31, purified by washing.

Coke C1/Ex. 231. Age of coal, under 7 months.

Dry coal coked, 85 lbs. Water as coked, 7.6%. Charged Jan. 6, and coked 48 hours.

(a) Little or no shrinkage. Coke was much better and sounder than C1/Ex. 31; less crumbly though somewhat similar in appearance; a poor commercial coke. Contained a good deal of "white mould."

(b) Harder, cleaner, and less friable than C1/Ex. 31; very dense, breaks cleanly.

(c) Class—B.

*Coal Ex. 32.* Middle seam, Tantalus mine.

Coke C1/Ex. 32. Age of coal, under 7 months.

Dry coal coked, 95 lbs. Water as coked, 6.9%. Charged Jan. 6, and coked for 48 hours.

(a) Very like coke C1/Ex. 31. Hardly a commercial coke; more like hard mortar than coke, very heavy and contains many dirty spots.

(b) Dirty, friable agglomerate; no regular cleavage.

(c) Class—C. The Yukon cokes tested, especially the dirtier and unwashed ones, contain so much lime that on keeping they tend to disintegrate owing to the lime slaking and expanding.

*Coal Ex. 232.* Coal Ex. 32, purified by washing.

Coke C1/ Ex. 232. Age of coal, under 7 months.

Dry coal coked, 85 lbs. Water as coked, 5.6%. Charged Jan. 6, and coked for 48 hours.

(a) Coke not so good as C1/Ex. 231, although better than C1/ Ex. 32; might be used as a commercial coke; contains a lot of "white mould."

(b) Great improvement on C1/Ex. 32; very dense, not much breeze, but fracture not very regular.

(c) Class—B.

*Coal Ex. 33.* Lower seam, Tantalus mine.

Coke C1/Ex. 33. Age of coal, under 7 months.

Dry coal coked, 54 lbs. Water as coked, 12.6% Charged Jan. 6, and coked 48 hours.

(a) All the Yukon coal samples tested were chiefly coal dust, any lumps being small, and they were all difficult to moisten. Little shrinkage, sound coke to top of box; better than any of above Yukon cokes; a very fair commercial coke, probably fit for iron blast furnace although there is very little cellular structure; clean fracture, showing very curious concentric spherical markings; little or no "white mould."

(b) Dense, hard coke; not much breeze, but breaks up rather easily in any direction.

(c) Class—A.

*Coal Ex. 233.* Coal Ex. 33, purified by washing.

Coke C1/Ex. 233. Age of coal, under 7 months.

Dry coal coked, 52½ lbs. Water as coked, 9.9%. Charged Jan. 6, and coked 48 hours.

(a) Little or no shrinkage; good coke, very dense; very much the same as C1/Ex. 33, not very noticeably cleaner.

(b) Like coke C1/Ex. 33, but harder and sounder.

(c) Class—A.

COKING TESTS MADE IN BEEHIVE OVEN OF THE DOMINION COAL CO.,  
AT BRIDGEPORT NEAR GLACE BAY, N.S., JANUARY, 1909.

All the boxes coked here were charged into the oven on Jan. 18, and were coked for 72 hours; unwashed slack coal from Lingan colliery was being coked in the oven at the time.

Preliminary Tests—Comparison of Open Oven and Box Cokes.

A box was filled with wet slack coal such as was charged into the oven, and the coke produced was compared with a typical sample of the coke made at the same time in the open oven.

*Box Coke, C81.*

(a) Coke very bubbly on the top; broke up and tumbled out of the box easily; a good commercial coke, but would be greatly improved by washing the coal.

(b) Very pretty coke, open texture, not very strong, but does not produce much breeze.

(c) A mere trace more compact than coke from the open oven, but otherwise the cokes are the same.

*Open Oven Coke, C82.*

(b) Not so pretty as C81, possibly not quite so strong, otherwise almost identical.

(c) Like C81, but a mere trace less compact.

*Coking Tests of Regular Coals.*

*Coal 2035 SP.* Dominion Coal Co., Phalen seam, Dominion No. 5, N.S.

Coke C2/2035 SP. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 45 lbs. Water as coked, 6.5%.

(a) Coke broke up somewhat in turning out of box. A good commercial coke; bottom half shiny black and large cell structure, top half steel grey and denser coke with a good deal of sooty deposit.

(b) Open cellular structure, dark coloured, produces a good deal of breeze. Weaker than the coke from same coal in Otto-Hoffman oven.

*Coal 2008.* Main seam, Acadia colliery, N.S.

Coke C2/2008. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked,  $48\frac{1}{2}$  lbs. Water as coked, 7.8%.

(a) Coke a little burned in one spot. Coke broke up into several pieces when taking out of box, cleavage from top to bottom. A good strong coke, sound from top to bottom, but shows signs of slate.

(b) Good strong coke, hard and bright at top, black at the bottom.

*Coal 6.* Cumberland Ry. & Coal Co., No. 3 colliery, Springhill, N.S.

Coke C2/6. Age of coal, under  $21\frac{1}{2}$  months.

Dry coal coked,  $47\frac{1}{2}$  lbs. Water as coked, 5.2%.

(a) Coke very crumbly, came out of box in one cake together with a quantity of loose stuff; not a commercial coke. No sample kept.

*Coal 28.* West Canadian collieries, No. 1 seam, Lille colliery, Alta.

Coke C2/28. Age of coal, under 8 months.

Dry coal coked, 49 lbs. Water as coked, 10.1%.

(a) Coke came whole out of box. Showed unfused lumps on all faces; broke up rather easily into small lumps.

(b) Distinctly worse than coke from the same coal coked in Otto-Hoffman or Bernard ovens.

*Coal 34.* International Coal & Coke Co., Coleman, Alta., No. 2 seam, Denison colliery.

Coke C2/34. Age of coal, under 8 months.

Dry coal coked,  $52\frac{1}{2}$  lbs. Water as coked, 9.6%.

(a) Coke very crumbly, especially at the bottom where there was a lot of loose dust. Not a commercial coke.

(b) Dirty, friable coke, not properly bonded, produces a great deal of breeze.

*Coal 31.* Crowsnest Pass Coal Co., No. 3 mine, Michel colliery, B.C.

Coke C2/31. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 51 lbs. Water as coked, 10.2%.

(a) Coke came out of box in two pieces, having simply cracked vertically across the centre. Very dense, shows pieces of original coal or slate unfused; a little crumbly at the top; slight tendency towards vertical cleavage, but breaks fairly easily across also. Like other Beehive cokes made, not thoroughly coked through, shows "black ends" at the bottom.

(b) Like coke from same coal in Otto-Hoffman oven in appearance but softer.

*Coal 26.* Crowsnest Pass Coal Co., No. 5 mine, Coal Creek, Fernie, B.C.

Coke C2/26. Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked,  $56\frac{1}{2}$  lbs. Water as coked, 11.6%.

(a) Coal was very dusty. Coke appeared cracked upon the top, but only broke in two when taken out of box. Showed unfused lumps on all outside surfaces and some inside. Breaks up rather easily.

(b) Not so strong as the cokes from the same coal in Otto-Hoffman and Bernard ovens, softer and blacker in appearance.

#### COKING TESTS IN THE BERNARD AND BAUER OVENS OF THE

NOVA SCOTIA STEEL & COAL CO., AT SYDNEY MINES,

N.S., JANUARY, 1909.

All the tests at Sydney Mines were made in Batteries 1 and 2 of Bernard ovens, except in the case of two boxes which were coked in Bauer ovens; the boxes, with 4 exceptions, were coked for 48 hours. Mixed washed coal from Mines 1 and 3 of the Nova Scotia Steel & Coal Co. was being coked in the ovens at the time the tests were made; this is referred to as N. S. S. & C. Co. coal.

Preliminary Tests—Comparison of Bernard and Bauer Ovens, also of Open Oven and Box Coke.

Two boxes were similarly filled with N. S. S. & C. Co. coal and two with D. I. & S. Co. coal; one of each of the pairs was coked in a Bernard oven and the other in a Bauer oven. Two samples were also taken of the open oven coke from the Bernard oven.

Difficulty was experienced in pushing the Bauer oven on account of a soft spot in the vicinity of the two boxes; this was due either to the oven having been a little cool, or, more probably, to an extra wet lorry of coal.

*Coke C86* from N. S. S. & C. Co. coal coked in Bernard oven 83 Jan. 23.

Wet coal coked, 47 lbs. Yield from wet coal, 58.2%.

(a) A good deal of shrinkage, sound coke to top, breaks up into bigger pieces than in the open oven where it breaks up into more rod-like pieces. The bottom half was very good, if anything better than the regular open oven coke, but the upper half was more cellular; the average would be about the same as the open oven coke.

(b) Fairly strong coke, open cellular structure, not very bright.

(c) A trace brighter than the open oven cokes C97 and C98, possibly due to better quenching.

*Coke C88* from N. S. S. & C. Co. coal coked in Bauer oven 18 on Jan. 25.

Wet coal coked, 45½ lbs. Yield from wet coal, 61.2%.

(a) Good coke and sound to top, nice bright coke. Could not see any difference between this and the corresponding Bernard coke, C86, except that the bottom and top halves of the coke were more alike in C88.

(b) Very much the same as C86, possibly a trace brighter.

(c) A mere trifle worse than C86, but a trace brighter than the open oven cokes C97 and C98.

*Coke C87* from D. I. & S. Co. coal coked in Bernard oven 83, Jan. 23. Wet coal coked, 49½ lbs. Yield from wet coal, 65.4%.

(a) A good deal of shrinkage, came out of box rather easily. A good coke, sound to top, regular cleavage.

(b) Contains a considerable amount both of silvery and of sooty coke; slightly stronger than the corresponding Bauer coke.

*Coke C89* from D. I. & S. Co. coal coked in Bauer oven 18, Jan. 25. Wet coal coked, 46½ lbs. Yield from wet coal, 68.9%.

(a) Good coke, sound to top; rather more of the large cell structure at the top than usual, this is said to be characteristic of the Bauer oven coke. The fracture of the coke in the box was more vertical than in

the case of the Otto-Hoffman cokes, probably due to the greater width of the Bauer oven.

- (b) Fairly good coke, contains a good deal of smut.
- (c) Almost identical with C 87.

*Coke 97* from N. S. S. & C. Co. coal, coked in open Bernard oven.

Sample was taken from coke made towards the top of a Bernard oven.

(b) Very much like coke from the same coal coked in boxes in Bernard and Bauer ovens, C86 and C88. Contains a certain amount of soot.

*Coke 98* from N. S. S. & C. Co. coal, coked in open Bernard oven.

Sample was taken from coke made towards the bottom of a Bernard oven.

- (b) Like C97, but contained a good deal more soot.
- (c) Better than C97.

#### *Final Coking Tests of Regular Coals.*

*Coal 38.* Dominion Coal Co., Phalen seam, Dominion No. 1, N.S.

*Coke C3/38.* Age of coal, 7 months.

Dry coal coked, 55 lbs. Water in coal as coked, 10%. Charged to oven, Jan. 26.

- (a) Good coke, regular cleavage, fit for anything.
- (b) Good, strong coke, very marked cleavage.
- (c) Not so good as the corresponding Otto-Hoffman coke, C1/38, which was classed +A.

*Coal 2038.* Fresh sample of coal like 38.

*Coke C3/2038.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 47 lbs. Water as coked, 6.7%. Coked with C3/38.

(a) Good coke, regular cleavage; came out of box easily. Was regarded as better than C3/38, because it contained more silvery and less black coke.

(b) Very like C3/38, but not quite so strong, contained more soot and more silvery coke.

- (c) Class—A. Not completely coked.

*Coal 39.* Lingan seam, Dominion No. 12, N.S.

*Coke C3/39.* Age of coal, 7 months.

Dry coal coked, 48½ lbs. Water as coked, 7.9%. Charged into oven Jan. 26.

(a) Had some difficulty in removing from box. An excellent coke, if anything slightly better than two preceding cokes.

(b) Practically the same as corresponding Otto-Hoffman coke, C1/39.

- (c) Not so good as C1/39.

*Coal 2039.* Fresh sample of coal like 39.

*Coke C3/2039.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 46 lbs. The box of this coal coked with C3/39 had been destroyed in the oven; the above box was filled by E. Stansfield, but was coked after he had left Sydney Mines on Jan. 30 and forwarded unopened to Montreal by Mr. J. McClelland, coke oven superintendent.

(a) Coke quite good, regular fracture, some long rods of coke formed.

(b) Like coke from coal 39 coked in Otto-Hoffman and Bernard ovens, but slightly stronger and brighter.

(c) Class — A.

*Coal 13.* Nova Scotia Steel & Coal Co., Sydney Mines, N.S., No. 1 colliery.

*Coke C3/13 (2).* Age of coal, under  $17\frac{1}{2}$  months.

Dry coal coked, 50 lbs. Water as coked, 5.0%. Charged into oven, Jan. 26.

(a) Very good looking coke, but breaks up very easily.

(b) Good, open cellular coke, but not very strong.

(c) Class — A.

*Coke C3/13 (1).* Age of coal, under  $17\frac{1}{2}$  months.

Dry coal coked, 52 lbs. The box of coal 2013, coked together with the above box of coal 13, was destroyed in the oven; extra boxes of coals 13 and 2013, therefore, were filled by E. Stansfield but coked after he had left Sydney Mines, as was described under C3/2039.

(a) Fair coke, regular fracture, but broke across very easily; contains visible slate, and shows a number of rust spots due to the coke having been left wet for some time.

(b) Same as C3/13 (2).

(c) Class — A.

*Coal 2013.* This was supposed to be a sample of fresh coal like coal 13. Actually the slack coal supplied was found to have a far higher ash content than the original sample of screened coal.

*Coke C3/2013.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 51 lbs. Coked with C3/13 (1).

(a) Fair coke, but very friable, probably due to the amount of slate, etc., present; also showed rust spots owing to having been left wet. Original fracture in box quite regular. Coke very little different from C3/13, a trace more fragile, and more slaty, but possibly brighter.

(b) Like coke C3/13, but breaks up smaller.

(c) Class — A. Slightly worse than C3/13 as more friable due to presence of slate.

*Coal 12.* No. 3 colliery, Sydney Mines, N.S.

*Coke C3/12.* Age of coal, under  $17\frac{1}{2}$  months.

Dry coal coked, 52 lbs. Water as coked, 8.2%. Charged into oven, Jan. 26.

(a) Box was badly squeezed in oven. Black and friable coke, not well bonded at the top, but good coke at the bottom. Said to be better coke than C3/2012 or than could ordinarily be made from coal from this mine by itself.

(b) Like the corresponding Otto-Hoffman coke, C1/12, possibly a trace harder.

(c) Not so good as C1/12, which was classed +B.

*Coal 2012.* Slack coal from No. 3 colliery, Sydney Mines, N.S. (See note to coal 2013).

*Coke C3/2012.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 50 lbs. Water as coked, 7.2%. Coked with C3/12.

(a) Box was placed too near end of oven and was badly burned. A black coke which easily breaks up into small pieces; too weak to use alone in an iron blast furnace.

(b) Like C1/12 and C3/12, but more fragile and produces more breeze; contains considerable visible slate.

(c) Class B. Very friable.

*Coal 10.* Canada Coals & Ry. Co., Joggins colliery, N.S.

*Coke C3/10.* Age of coal, under  $21\frac{1}{2}$  months.

Dry coal coked, 51 lbs. Water as coked, 6.8%. Charged into oven, Jan. 25, and coked 50 hours.

(a) A grey coloured coke, only just coked; a lot of loose material at the top and the bulk very weak. A great deal of slate showing, also some sulphur. If the coal was washed free from slate it might produce commercial coke.

(b) Dirty, weak coke; no regular fracture; makes a lot of breeze.

(c) Class B. Scarcely up to eastern standards, but would pass in the west.

*Coal 3010.* Fresh sample of coal like 10.

*Coke C3/3010.* Age of coal, under 1 month.

Dry coal coked, 52 lbs. Water as coked, 6.8%. Coked with C3/10.

(a) Some good coke, but a great deal of very black or dull grey; less slate visible than in C3/10. A commercial coke, though not good.

(b) Dull black coal, harder and makes less breeze than C3/10.

(c) Class+B. Darker in colour than C3/10, but harder and less friable.

*Coal 11.* G. H. King, Kings mine, Minto, N.B.

*Coke C3/11.* Age of coal, under  $21\frac{1}{2}$  months.

Dry coal coked,  $57\frac{1}{2}$  lbs. Water as coked, 7.3%.

(a) Box damaged in oven, only fragment of coke left in broken box, but it looked to be good coke.

(b) Hard coke, no regular fracture. Not enough coke left to make physical tests.

(c) Class — A. Dense, strong coke.

*Coke 48.* Leitch Collieries Ltd., No. 1 or Byron seam, Passburg, Alta.  
Coke C3/48. Age of coal, under  $5\frac{1}{2}$  months.

Dry coal coked, 56 lbs. Water as coked, 6.5%. Charged into oven, Jan. 27.

(a) The box was apparently coked wrong side up. A fair commercial coke; the outside layer, 3" or 4" thick, was very bright, the inside distinctly dull.

(b) Like corresponding Otto-Hoffman coke, but slightly more fragile.

*Coal 32.* Hillcrest Coal & Coke Co., Hillcrest, Alta.

Coke C3/32. Age of coal, under 8 months.

Dry coal coked,  $55\frac{1}{2}$  lbs. Water as coked, 6.9%. Charged into oven, Jan. 26.

(a) A passable commercial coke, but very slaty and no regular cleavage; it looked as though it would come out of the box in one piece, actually it was very difficult to get out and broke up into small pieces.

(b) Like corresponding Otto-Hoffman coke.

*Coal 33.* West Canadian Collieries Co., No. 1 seam, Bellevue colliery, Alta.

Coke C3/33. Age of coal, under 8 months.

Dry coal coked, 49 lbs. Water as coked, 6.6%. Charged into oven, Jan. 26.

(a) A solid lump of coke, except for one crack across the middle; no regular cleavage, very hard to get out of box. A fair coke cementing together slate and unfused particles of coal, more bonded at the bottom than at the top.

(b) Not so good as the corresponding Otto-Hoffman coke, similar but not so strong.

*Coal 28.* West Canadian Collieries Co., No. 1 seam, Lille colliery, Alta.  
Coke C3/28. Age of coal, under 8 months.

Dry coal coked, 58 lbs. Water as coked, 8.5%. Charged into oven Jan. 27.

(a) The box was squeezed in oven; coke quite sound and only one crack across, no regular cleavage; very difficult to get from box. Coke very fair, but not well bonded.

(b) Similar to corresponding Otto-Hoffman coke.

*Coal 30.* Crowsnest Pass Coal Co., No. 7 mine, Michel colliery, B.C.

*Coke C3/30.* Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 54 lbs. Water as coked, 5.9%. Charged into oven, Jan. 27.

(a) Not a commercial coke; a very little had caked, but most of it was a loose powder. No sample kept.

*Coal 29.* No. 8 mine, Michel colliery, B.C.

*Coke C3/29.* Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked,  $54\frac{1}{2}$  lbs. Water as coked, 8.2%. Charged into oven, Jan. 26.

(a) Cleavage of coke showed that the box had not been lying square across the oven. Coke split into big pieces, some loose coke at the top of the box; not very good anywhere, but a possible commercial coke.

*Coal 26.* Crowsnest Pass Coal Co., No. 5 mine, Coal Creek, Fernie, B.C.

*Coke C3/26.* Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked,  $54\frac{1}{2}$  lbs. Water as coked, 10.3%. Charged into oven, Jan. 25, and coked for 50 hours.

(a) A trace of loose on the top, otherwise good, strong coke from bottom to top. Heavy coke, very little cell space, some visible slate.

(b) Breaks up rather easily, but makes very little breeze. In general, like corresponding Otto-Hoffman coke.

*Coal 18.* Western Fuel Co., Upper seam, No. 1 mine, Nanaimo, B.C.

*Coke C3/18.* Age of coal, under 9 months.

Dry coal coked, 52 lbs. Water as coked, 8.0%. Charged into oven, Jan. 27.

(a) Not a commercial coke; had caked at sides and bottom, but mostly a loose dry powder with a limy smell.

*Coal 21 M.* Wellington Colliery Co., Cumberland, B.C., Lower seam, Mines 4 and 7, Comox colliery.

*Coke C3/21 M.* Age of coal, under  $8\frac{1}{2}$  months.

Dry coal coked, 53 lbs. Water as coked, 7.6%. Charged into oven, Jan. 26.

(a) Very solid in box. A poor commercial coke, fairly regular cleavage, hard and dense, but very dirty.

(b) Much the same as the corresponding Otto-Hoffman coke, but a trace less compact in the hardest parts.

*Coal Ex. 232.* White Pass & Yukon Ry. Co., Middle seam, Tantalus mine, Yukon Territory. Coal had been washed.

*Coke C3/Ex. 232.* Age of coal, under  $7\frac{1}{2}$  months.

Dry coal coked,  $50\frac{1}{2}$  lbs. Water as coked, 16.4%. Charged to oven, Jan. 23.

(a) Dry, crumbly, mortar-like material, of no commercial value.

COKING TESTS IN THE BERNARD OVENS OF THE WEST CANADIAN  
COLLIERIES CO., AT LILLE, ALTA., JULY AND AUGUST, 1909.

16 boxes of coal were coked at Lille, eight in one oven and eight in another; they were charged into the oven on August 3 and were coked for 48 hours; washed slack coal from the Lille colliery was being coked in the ovens at the time.

Preliminary Test—Comparison of Open Oven and Box Coke.

*Box Coke C120.* A box of wet washed slack coal from the Lille colliery, such as was being charged into the oven at the time, was coked as usual. Weight of wet coal, 47 lbs. Yield of dry coke from wet coal, 70.4%.

(b) Regular cleavage, small shrinkage, good appearance, compact coke, does not produce much breeze on breaking.

(c) Class A.

*Open Oven Coke C121.* A sample of coke was taken from the product of the two ovens in which the boxes were coked.

(b) Coke appears to contain slightly less slate than the box coke, otherwise much the same; not very good colour.

(c) Class A.

*Final Coking Tests of Regular Coals.*

*Coal 2048.* Leitch Collieries, Ltd., No. 1 or Byron seam, Passburg, Alta.

*Coke C4/2048.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 51 $\frac{1}{2}$  lbs. Water as coked, 8.3%.

(a and b) Not much shrinkage; no regular fracture, produces breeze when broken, a little visible slate.

(c) Class +B.

*Coal 2032.* Hillcrest Coal & Coke Co., Hillcrest colliery, Alta.

*Coke C4/2032.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 50 $\frac{1}{2}$  lbs. Water as coked, 10%.

(a and b) Not much shrinkage and very little fracture; irregular fracture producing breeze when broken. Fairly hard coke, contains visible slate.

(c) Class -A.

*Coal 2033.* West Canadian Collieries Co., No. 1 seam, Bellevue colliery, Alta.

*Coke C4/2033.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 51 lbs. Water as coked, 9.2%.

(a and b) Not much shrinkage, no regular fracture; makes breeze when broken, fairly compact and strong coke.

(c) Class +B.

*Coal 2028.* West Canadian Collieries Co., No. 1 seam, Lille colliery, Alta.

Coke C4/2028. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 49 lbs. Water as coked, 10.5%.

(a and b) Fair shrinkage and fair fracture, but friable coke and, therefore, it produces breeze; contains visible slate.

(c) Class +B.

*Coal 2034.* International Coal and Coke Co., No. 2 seam, Denison colliery, Coleman, Alta.

Coke C4/2034. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 56 lbs. Water as coked, 9.7%.

(a and b) Not much shrinkage, fracture irregular, very hard to remove from box; makes a lot of breeze and contains a good deal of visible slate.

(c) Class -B.

*Coal 2034 SP.* No. 4 seam, Denison colliery, Coleman, Alta.

Coke C4/2034 SP. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 50 $\frac{1}{2}$  lbs. Water as coked, 9.2%.

(a and b) Slight shrinkage, no regular fracture, hard to get from box, a lot of visible slate.

(c) Class B.

*Coal 2031.* Crowsnest Pass Coal Co., No. 3 mine, Michel colliery, B.C.

Coke C4/2031. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 50 lbs. Water as coked, 8.8%.

(a and b) Not much shrinkage, fairly regular fracture, not much breeze, good, sound coke to top.

(c) Class A.

*Coal 2029.* No. 8 mine, Michel colliery, B.C.

Coke C4/2029. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 51 lbs. Water as coked, 12.3%.

(a and b) Dense, hard coke, sound to top of box, fair shrinkage, good fracture, hard to break, does not produce much breeze.

(c) Class A.

*Coal 51.* Hosmer Mines, Ltd., No. 2 seam south, Hosmer, B.C.

Coke C4/51. Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 51 lbs. Water as coked, 8.0%.

(a and b) Very weak coke, no regular fracture, produces a lot of breeze, contains a good deal of slaty material or unfused coal.

(c) Class +C.

*Coal 52.* No. 6 seam south, Hosmer, B.C.

*Coke C4/52.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 48 $\frac{1}{2}$  lbs. Water as coked, 7.2%.

(a and b) Good commercial coke, not much breeze produced on breaking, regular cleavage, slight shrinkage, good colour except in centre.

(c) Class A.

*Coal 53.* No. 8 seam south, Hosmer, B.C.

*Coke C4/53.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 46 lbs. Water as coked, 12.8%.

(a and b) A very nice looking coke, very regular fracture, breaks rather easily along fracture lines to form small pieces, but produces very little breeze. Showed rather peculiar markings in the form of concentric spherical rings.

(c) Class A.

*Coal 2027.* Crowsnest Pass Coal Co., No. 2 mine, Coal Creek, Fernie, B.C.

*Coke C4/2027.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 50 lbs. Water as coked, 10.3%.

(a and b) Good looking but friable coke, slight shrinkage, a good deal of breeze formed.

(c) Class B.

*Coal 2026.* No. 5 mine, Coal Creek, Fernie, B.C.

*Coke C4/2026.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 50 lbs. Water as coked, 8.8%.

(a and b) Dense, good looking coke, fair shrinkage, regular fracture sound to top, does not produce much breeze; shows slight spherical markings, also some visible slate.

(c) Class — A.

*Coal 2020.* Wellington Colliery Co., Wellington seam, Extension colliery, B.C.

*Coke C4/2020.* Age of coal, under 4 months.

Dry coal coked, 43 lbs. Water as coked, 9.8%.

(a and b) Fair coke, breaks up fairly easily, but does not produce much breeze.

(c) Class — A.

*Coal 2018.* Western Fuel Co., Upper seam, No. 1 mine, Nanaimo, B.C.

*Coke C4/2018.* Age of coal, under 4 months.

Dry coal coked, 44 lbs. Water as coked, 8.5%.

(a and b) Considerable shrinkage, fair cleavage, very friable, especially at the top; has a limy smell and shows "white mould."

(c) Class B.

COKING TESTS MADE IN THE BEEHIVE OVENS OF THE INTERNATIONAL  
COAL AND COKE CO., AT COLEMAN, ALTA., AUGUST 1909.

Three boxes were charged into one oven, and three boxes and one sack into another on the morning of August 7. The coking of the charge in the ovens appeared to be completed during the night of August 9-10 and the ovens were then closed. They were quenched and drawn on August 10, 74 hours after they were charged. Slack coal from the Denison colliery, mixed in the proportion of 2 parts from No. 4 seam to 1 part from No. 2 seam, was being coked in the ovens at this time; this coal was dry, so the boxes of coal coked here were also dry. The boxes were coked on end; the regular fracture lines in consequence sloped inwards from the perforated lid and downwards.

Preliminary Tests—Comparison of Open Oven and Box Cokes.

*Box Coke C122.* Coal was taken from the top of cars coming out of the mine, as nearly as was possible without weighing, in the proportion of 2 parts from No. 4 seam to 1 part from No. 2 seam. The coal was well mixed together; any big lumps found were broken up, and a box filled with the raw coal and coked.

(a and b) Dense soft coke, does not appear completely coked; slight regular fracture, but breaks in all directions; some visible slate.

(c) Class+B.

*Open Oven Coke C123.* A sample of coke was taken from the oven in which the above box was coked. Physical tests as usual were made on this sample, but no notes were made as to its appearance.

Preliminary Tests—Coking Coal in a Sack.

Samples of coal are tested by coke manufacturers most frequently by coking them in a wooden box or barrel in a regular oven; a sack has been recommended as being preferable to a box on account of the ease with which the gases can pass out, and because the coal inside is subjected to exactly the same pressure as the surrounding coal. A sack of coal was coked in a Beehive oven at Coleman; it was found that it was quite easy to separate at least the bulk of the coke produced from the surrounding coke, so that in this case the method was satisfactory. Very poor coke probably could not have been recovered, and neither the sack nor the wooden box method allows the yield of coke to be determined.

*Final Coking Tests of Regular Coals.*

*Coal 2032.* Hillcrest Coal & Coke Co., Hillcrest colliery, Alta.

*Coke C5/2032.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 53 lbs.

(a and b) Slight shrinkage, fracture fair, but coke very easily broken; colour bright at top but dull at bottom, rather large amount of visible slate.

(c) Class +B.

*Coal 2034 SP.* No. 4 seam, Denison colliery, Coleman, Alta.

*Coke C5/2034 SP.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 55 lbs.

(a and b) Not much shrinkage, no regular fracture; a good deal of visible slate, fair colour at the top.

(c) Class +B.

*Coal 52.* Hosmer Mines, Ltd., No. 6 seam south, Hosmer, B.C.

*Coke C5/52.* Age of coal, under  $\frac{1}{2}$  month.

Dry coal coked, 53 lbs.

(a and b) Fairly even fracture, considerably cracked across the seams, not much breeze produced, good colour, very little visible slate.

(c) Class A.

*Coal 2026.* Crowsnest Pass Coal Co., No. 5 mine, Coal Creek, Fernie, B.C.

*Coke C5/2026.* Age of coal, under  $\frac{1}{2}$  month.

(a and b) Good coke, very nice appearance, fair shrinkage, regular fracture, considerably broken up along fracture lines and came easily out of box; breaks rather easily into small pieces, but does not produce much breeze.

(c) Class A.

*Coal 2020.* Wellington Colliery Co., Wellington seam, Extension colliery, B.C.

*Coke C5/2020.* Age of coal, under 4 months.

Dry coal coked, 48 lbs.

(a and b) Fair shrinkage, regular fracture, broke up easily into prisms of very bright, good looking coke.

(c) Class A.

## TEMPERATURES OF COKE IN AN OTTO-HOFFMAN OVEN.

An attempt was made to record the temperatures at different points inside the charge in an Otto-Hoffman coke oven throughout the entire period of coking; the difficulties of the task undertaken, however, were not sufficiently foreseen and guarded against, and the results obtained are too unreliable to be worth publishing. The methods employed and the difficulties encountered are described below.

Six holes were drilled through the door at the quenching platform end of the oven chosen for the tests; three of these were spaced about 18" apart down the centre line of the door, the other three were at the same

levels but near one side of the door. The observation hole near the top made a seventh opening in the door through which a pyrometer fire end could be introduced; three of the charging hole covers on the top of the oven were also drilled to allow the introduction of a pyrometer. The ten holes were stopped with clay when not in use.

The pyrometer fire ends employed were of nickel and iron, and were about 1" external diameter; 4 ft. rods were used for the end temperatures, and 6 ft. rods for the temperatures on the top of the coke.

The test was begun half an hour after a fresh charge of coal had been introduced into the oven; the temperature was taken at each of the ten points in order, and this operation repeated every half hour until the coking was completed. A hole about 3 feet deep was made into the charge opposite the hole in the door by means of an iron rod, and the fire end then pushed to the bottom of the hole; through the holes in the charging doors on the top a fire end was put down 2" or 3" into the top of the charge.

The pyrometer fire end had in every case to pass through a hotter zone before it reached the point at which the temperature was to be determined; as it was made of metal, heat was fairly rapidly conducted along it from the hot portion to the nickel-iron junction at the end, and, therefore, the true temperature at that point was not recorded. To obviate this difficulty the fire ends were always left in for one minute only; this time was possibly all right for the lower temperatures at the beginning, but was not sufficient for the higher temperatures reached later on, since it was found that a different temperature was recorded according to whether the fire end was introduced hot or cold. As the temperature continued to rise more or less rapidly for some time if a fire end was left in for a longer period, it did not appear to be possible to select any length of time which would be sufficient to allow them to attain to the correct temperature without heat conduction along them vitiating the result.

The holes made into the charge opposite the holes in the door became enlarged by oxidation and mechanical abrasion until they were comparatively large conical holes, and in one case two holes side by side became united; the temperatures at the bottom of such holes could not be expected to be the same as in similar positions in the solid coke.

Four chemists from the laboratory of the Dominion Iron and Steel Co. took it in turns to take the pyrometer readings during the forty-eight hours for which the charge in the oven was coked.

## ANALYSES OF GAS FROM BERNARD OVENS AT SYDNEY MINES.

In the Bernard ovens at Sydney Mines the gases given off from the coal as it is coked are mixed with air and burned in the flues around the ovens, the hot products of combustion are led away in large flues and used to heat a battery of boilers. Samples of the gas given off during the pro-

gress of the coking were taken off from the top of the charges in the ovens by means of a long iron pipe passed through the observation hole in the door of the oven. Samples of gas were also taken from the flues leading from the ovens to the boilers, and from the flue through which the gases pass after leaving the boilers. Five holes were drilled into the flues: No. 1 was in the flue from No. 1 battery, just where it left the battery and carried the mixed gases from all the ovens; No. 2 was in a corresponding position in the flue from No. 2 battery; No. 3 was in the gas inlet into the boiler nearest to No. 1 battery; No. 4 was in the gas inlet into the boiler nearest to battery No. 2; and No. 5 was in the exit flue from the boilers.

An iron pipe of about  $\frac{3}{8}$ " bore and 20 feet long was used to withdraw gases from the top of an oven, a shorter pipe was used to take samples from the underground flues. Gas was aspirated through the pipe and connecting tubes, and through a glass sample tube of about 20 c.c. capacity, by means of a rubber hand pump or by a couple of large bottles, containing water, used as an aspirator, at least 5 litres of gas being drawn through. The gas sample tubes were shaped like a cylindrical pipette for liquids, but had a constriction in the tube on either side of the bulb; when they were filled with the desired gas they were temporarily closed by spring clips on the connecting rubber tubes, taken to the laboratory close by and at once sealed off at the constrictions by means of a gas flame. The samples were analysed, in Montreal, over mercury in the Bone and Wheeler gas analysis apparatus.

The samples taken were as follows:—

1. January 28, 1909. Gas from oven 44 at 1.10 p.m. This oven was pushed at 1.30 p.m. and at once recharged.
2. Gas from oven 44 at 2.10 p.m., not a reliable sample.
3. Gas from oven 44 at 2.35 p.m.
4. Gas from oven 43 at 3.45 p.m.; this oven had been charged at about 6.30 p.m. the previous day. Had trouble with soot blocking up the sampling tubes.
5. Gas from oven 44 at 4.10 p.m.
6. January 29, 1909. Gas from hole 1 at 10.30 a.m.
7. Gas from hole 3 at 11.00 a.m.
8. Gas from hole 5 at 11.30 a.m.
9. Gas from hole 4 at noon.
10. Gas from hole 2 at 1.20 p.m. Battery No. 2 had just been completely recharged when this sample was taken.
11. Gas from hole 4 at 1.40 p.m.
13. Gas from hole 3 at 2.20 p.m.
14. Gas from hole 5 at 3.05 p.m.
15. Gas from oven 87 at 3.30 p.m. This oven had been charged at 3.05 p.m., it had not yet been luted on the windward end when the sample was taken.

16. Gas from oven 88 at 3.50 p.m. This oven had been charged at about 3.00 p.m. the previous day. The wind was blowing a considerable quantity of gas out of the end of the oven at the time the sample was taken.

17. Gas from oven 22 at 4.10 p.m. This oven had been charged at 10.00 a.m. that day.

Table II gives the analysis of the gases from the ovens and Table III the analysis of the gases from the flues.

TABLE II  
GAS FROM OVENS

Sample number.....	2	15	3	5	17	4	16	1
Oven.....	44	87	44	44	22	43	88	44
Time of sampling after charging hours	$\frac{1}{2}$	$\frac{1}{2}$	1	$2\frac{1}{2}$	$6\frac{1}{4}$	$21\frac{1}{4}$	$24\frac{3}{4}$	$47\frac{1}{2}$
Hydrogen.....%	7.7	36.3	29.2	27.7	42.4	30.0	29.8	0.7
Methane.....%	35.0	28.0	37.7	15.1	28.7	7.8	4.9	0.2
Ethylene.....%	7.7	6.9	3.6	2.9	13.5	0.3	0.0	0.0
Carbon monoxide.....%	2.5	7.6	1.7	5.5	4.7	9.1	15.0	5.9
Carbon dioxide.....%	3.9	4.3	3.4	7.6	4.7	6.4	4.8	10.0
Oxygen.....%	8.4	0.4	4.5	0.6	0.0	0.1	0.4	0.3
Nitrogen.....%	34.8	16.5	19.9	40.6	6.0	46.3	45.1	82.9
Inflammable gas.....%	52.9	78.8	72.2	51.2	89.3	47.2	49.7	6.8
Gross calorific value—B.T.U. per cub. ft.....	506	532	534	304	655	209	193	23
Net calorific value—B.T.U. per cub. ft.....	458	477	477	272	590	185	173	22

TABLE III  
GAS FROM FLUES

Sample number.....	6	10	7	13	9	11	8	14
Hole number.....	1	2	3	3	4	4	5	5
Hydrogen.....%	10.3	22.4	3.2	0.0	7.9	14.1	0.0	0.0
Methane.....%	1.3	0.4	1.2	0.0	0.7	0.0	0.0	0.0
Ethylene.....%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbon monoxide.....%	6.0	9.2	0.4	0.0	1.2	2.5	0.0	0.0
Carbon dioxide.....%	1.6	2.8	10.0	10.6	12.1	8.0	7.3	7.0
Oxygen.....%	7.3	0.0	0.2	2.3	0.1	2.0	10.8	11.0
Nitrogen.....%	73.5	66.2	85.0	87.1	78.0	73.4	81.9	82.0
Inflammable gas.....%	17.6	32.0	4.8	0.0	9.8	16.6	0.0	0.0
Gross calorific value—B.T.U. per cub. ft.....	66	106	24	0	36	54	0	0
Net calorific value.....								
Net calorific value—B.T.U. per cub. ft.....	59	94	21	0	32	46	0	0

## THE STRENGTH OF COKE

In the report on coking experiments, Vol. I, Part VI, pages 223-5, there is a discussion of the relation of the strength of coke to its usefulness; and a description of a method of testing this strength and calculating the results.

The method used was, in brief, to crush the sample to just pass through a 1" screen; to remove all fines which would pass a  $\frac{1}{2}$ " screen; and to subject 500 grams of the material between 1" and  $\frac{1}{2}$ " to a pressure of 4200 pounds in a cylinder of nearly  $5\frac{1}{4}$ " diameter. After leaving this pressure of 200 pounds per square inch on the sample for 2 minutes, the material was removed and sieved through  $\frac{1}{2}$ ",  $\frac{5}{16}$ ", and  $\frac{3}{16}$ " screens and the resultant products weighed. The strength factor was then determined by dividing<sup>1</sup> the quantities remaining on each of the respective sizes of sieves, by the size of the last sieve the material passed through, and adding the results. Thus, in a case cited in which 500 grams were taken, 347 grams were still larger than  $\frac{1}{2}$ ", *i.e.* passed 1"; 67 grams passed  $\frac{1}{2}$ "; 31 grams passed  $\frac{5}{16}$ "; and 55 passed  $\frac{3}{16}$ ", and the summation, therefore, equalled  $(347 \div 1) + (67 \div \frac{1}{2}) + (31 \div \frac{5}{16}) + (55 \div \frac{3}{16}) = 873 = \text{Strength Factor}$ .

It is obvious that the strength of any coke is greater as this figure is less, or, in other words, that the strengths vary more or less exactly as the reciprocals of the strength factor. If any one coke is then chosen as standard the relative strengths of the other cokes may be obtained by dividing their factors into that of the standard. The coke selected as standard for the tests reported in Vol. I had a factor of 674, therefore the coke given above has a relative strength of  $674 \div 873 = 0.772 = S$ .

Since Vol. I was written some very interesting and valuable experiments have been carried out by Stadler and others in Johannesburg,<sup>2</sup> and more recently by Bell, Ball, and others at McGill University, Montreal. The result of these experiments is to prove that if a partially crushed hard material, such as rock, be first separated by sieving into a series of grades or sized products, and the material in each of these grades weighed, and if thereafter the graded material be subjected to further crushing and then regraded, then the power consumed in this crushing will be found to be a function of the change in grade, *i.e.*, a function of the reduction in volume of the particles.

Stadler's original paper deals with this matter somewhat elaborately and recommends a particular series of sieve sizes and grades giving definite ratios of volumes, and, therefore, equally definite energy units for each grade, but it also points out the possibility of calculating the equivalent grade or energy unit of material sized or graded on sieves of any other dimensions. The work done more recently at McGill tends in a general way to confirm these conclusions by showing that the power actually con-

<sup>1</sup> By an error in printing in Vol. I, p. 224, the x sign was used in place of the  $\div$  sign. The results are however, correctly calculated.

<sup>2</sup> Stadler, Grading Analyses and their Applications. Bulletin, Institution of Mining and Metallurgy, London, May 19, 1910.

sumed in crushing several different kinds of rock to different degrees is proportional within reasonable limits to the change in grading.<sup>1</sup>

The actual consumption of power in crushing a given quantity of any rock depends, of course, not only on the reduction in grade but also on the strength or resistance to crushing of the rock concerned, and, therefore, if we wish to compare different rocks, the results of tests made on any particular kind of rock have to be corrected or reduced to a standard by multiplying by a coefficient experimentally determined for that rock. These coefficients have only been determined for a very few rocks and further work will, no doubt, prove that they vary considerably with rocks of the same kind from different localities. It is exceedingly likely also that the coefficient for each rock will be found to change as the crushing gets down to very fine sizes in which the crystalline structure influences the strength. A great deal of work will have to be done before the theory of rock crushing can be said to be completely proved and definitely reduced to a matter of practical calculation, but even the experiments already completed suffice to show that Stadler's method affords us a more accurate means than we have heretofore had of determining, either the strength of broken rock to resist further reduction in size, or, conversely, to determine by calculation the amount of power which has been exerted in crushing rock from some previous size to its present grade.

In reviewing the section of the main report dealing with the strength of coke,<sup>2</sup> it occurred to the writer that it would be well to re-determine the strengths by the Stadler method and to compare the results with the relative strengths  $S$  and  $S^2$  determined by the empirical method originally employed. Nine samples of coke were withdrawn from the Museum collection and crushed by the method already described, and average portions of the crushed fragments of each sized on the set of sieves originally used and the relative strength factors  $S$  and  $S^2$  calculated. The equivalent energy units of these sieves were then determined and the relative strength of the material was calculated by the Stadler method. As it was difficult to arrive theoretically at a satisfactory energy unit for the material under  $\frac{3}{16}$ ", all of which was lumped in one grade in the original tests, this material was screened in each of the 8 recent tests on a series of seven standard sieves, from 10 mesh down to 200 mesh, and the energy units determined for each grade. The results of these tests<sup>3</sup> are set forth in Table IV, which requires no further elucidation.

These tests show that the relative strength factor  $S$ , as originally determined, is not satisfactory, in that it does not sufficiently differentiate between a strong coke and a weak one. On the other hand, the square of this factor, or  $S^2$  is very fairly in accordance with the result of the more recent and more scientific method of testing, and closely in

<sup>1</sup> Ball, Bulletin, Institution of Mining and Metallurgy, London, October, 1911.

<sup>2</sup> Porter, See Vol. I, p. 223.

<sup>3</sup> These tests and the necessary calculations were made under the author's direction by Mr. E. E. Billington, B.Sc.

parallel with it in the cases of cokes of good commercial quality. The two methods are less in accordance in the cases of weak cokes, and it has, therefore, been thought desirable to tabulate the whole series of results of the original crushing trials, and to give not only the relative strengths,  $S$  and  $S^2$ , as already reported in the summary, but also the Stadler factors as calculated for the series.

The results of the original tests and of these re-calculations are given in extenso in Table VI, which needs no explanation except in regard to the determination of the Stadler factor for the material passing through the  $\frac{3}{16}$ " screen. As this material had all been discarded after the original tests, and as fresh samples of many of the cokes could not be had, it was necessary to assume a factor, and for this purpose the energy units were calculated for the fine portions of each of the eight coals tested, as per the central section of Table IV. The results are set forth in Table V, from which it will be seen that the Stadler factors for all these cokes range within the narrow limits between 11.0 and 13.1, and average almost exactly 12. This factor of 12 was, therefore, adopted and used in calculating the energy units given in column 13 of Table VI.

The above section applies only to the actual strength of the coke. In the tests reported in Vol. I it was found better to consider both the strength and the porosity of a coke when attempting to judge its commercial value from a physical standpoint. The values obtained by multiplying the square of the relative strength of each coke ( $S^2$ ) by its percentage cell space or porosity ( $P$ ) appeared to give the best commercial classification of the cokes.

TABLE IV

Tests of the strength of coke, being a comparison of Stansfield's and Stadler's factors as determined on eight selected samples, at McGill University, January-February, 1912

Coke Number			C <sub>3</sub> 26			C <sub>3</sub> 39			C <sub>1</sub> 21			C <sub>3</sub> 2038			C <sub>5</sub> 2034 SP.			C <sub>2</sub> 2008			C <sub>3</sub> 2013			C <sub>2</sub> 34			
Sieve opening	Stansfield factor on 500 gms.	Stadler factor on 100 gms.	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	Per cent over size	Stansfield value	Stadler value	
1"	1	0.83	82.8	414	0.69	75.4	377	0.62	77.4	387	0.64	72.4	362	0.60	68.6	343	0.57	63.2	316	0.52	47.4	237	0.39	20.6	103	0.17	
1 1/8"	2	3.68	11.8	118	0.43	16.0	160	0.59	12.4	124	0.46	16.4	164	0.60	13.6	136	0.50	18.0	180	0.66	22.8	228	0.84	21.8	218	0.80	
1 1/16"	1 1/16	5.75	2.2	35	0.13	4.2	67	0.24	4.4	70	0.25	4.4	70	0.25	7.4	118	0.43	8.4	134	0.48	10.8	173	0.62	18.2	291	1.05	
1 1/8"	1 1/8	8.2	2.2		0.18	2.6		0.21	4.2		0.34	3.9		0.32	7.1		0.58	6.7		0.55	10.9		0.89	24.7		2.03	
20	1 3/16	13.75	0.3		0.04	0.4		0.05	0.6		0.08	1.0		0.14	1.2		0.16	1.0		0.14	2.3		0.32	5.3		0.73	
30	1 1/2	17.0	0.1		0.02	0.2		0.03	0.3		0.05	0.4		0.07	0.5		0.08	0.5		0.08	1.2		0.20	2.3		0.39	
50	1 5/8	19.0	0.2	96	0.04	0.2	112	0.04	0.3	165	0.06	0.6	197	0.11	0.5	277	0.09	0.7	293	0.13	1.4	507	0.27	2.4	1072	0.46	
70	1 3/4	20.5	0.1		0.02	0.1		0.02	0.2		0.04	0.4		0.08	0.3		0.06	0.5		0.10	0.9		0.18	1.5		0.31	
120	1 7/8	22.5	0.2		0.04	0.2		0.04	0.2		0.04	0.4		0.09	0.3		0.07	0.6		0.13	0.9		0.20	1.4		0.31	
200	1 3/4	25.0	0.1		0.02	0.3		0.07	0.2		0.05	0.3		0.07	0.2		0.05	0.4		0.10	0.6		0.15	0.9		0.22	
-200	1 3/8	28.0	0.2		0.05	0.2		0.05	0.2		0.05	0.3		0.08	0.2		0.05	0.5		0.14	0.8		0.22	1.4		0.39	
Stadler's energy units—					1.66			1.96			2.06			2.41			2.64			3.03			4.28			6.86	
Total.....																											
Relative strength standard = 1.69					1.02			0.86			0.82			0.70			0.64			0.56			0.40			0.25	
Factor of strength.....				663			716			746			793			874			923				1145			1684	
Relative strength S standard = 674.....				1.02			0.94			0.90			0.85			0.77			0.73				0.59			0.40	
Square of relative strength—S <sup>2</sup> .....				1.04			0.88			0.81			0.72			0.59			0.53				0.35			0.16	

NOTE:—Standard coke referred to is explained in Vol. I, on page 225. Its Stadler total is taken as 1.69 and its relative strength as 674.

If these results be compared with the original tests made approximately three years ago, it will be found that while the samples show relatively the same order of strength, yet the weaker cokes have fallen off considerably as compared with the stronger; this is no doubt due to the weathering of the cokes themselves, which have been exposed in open trays. Minor discrepancies such as shown by C<sub>3</sub>26 in which the strength has apparently increased, are due to the fact that the second lot of samples had been selected for exhibition and were probably somewhat stronger than the average.

TABLE V  
Calculation of the Stadler factor for coke passing through a  $\frac{3}{16}$ " screen

Coke Number.....	C <sub>3</sub> 26	C <sub>3</sub> 39	C <sub>1</sub> 21	C <sub>3</sub> 2038	C <sub>5</sub> 2034SP.	C <sub>2</sub> 2008	C <sub>3</sub> 2013	C <sub>2</sub> 34
Per cent through $\frac{3}{16}$ " screen.....	3.4	4.2	6.2	7.3	10.4	10.9	19.0	39.9
Sum of Stadler values .....	0.41	0.51	0.71	0.96	1.14	1.37	2.43	4.84
Stadler Sum ÷ Per cent of material × 100 .....	12.0	12.1	11.5	13.1	11.0	12.5	12.8	12.1

TABLE VI

Detailed results of coke crushing tests arranged geographically by coal fields; with the relative strengths tabulated, as reported by Mr. Stansfield in the summary tables, Vol. I, Part VI, and also the Stadler values and energy units as recently determined.

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material.				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			$\mathcal{S}$	Stadler, standard = 1.69
SYDNEY COAL-FIELD.																
C 1/50.....	302 361	93 44	39 33	65 63	1 -1	965 886	926	0.729	0.50 0.60	0.68 0.32	0.45 0.38	1.56 1.51	3.19 2.81	3.00	0.53	0.56
C 1/36.....	382	61	25	32	0	754	754	0.894	0.63	0.45	0.29	0.77	2.14	2.14	0.80	0.79
C 1/2036...	383 393	46 50	25 22	46 32	0 3	799 749	774	0.870	0.64 0.65	0.34 0.37	0.29 0.25	1.10 0.77	2.37 2.04	2.22	0.76	0.76
C 1/35.....	385 371	42 48	26 26	48 54	-1 1	803 843	823	0.819	0.64 0.62	0.31 0.35	0.30 0.30	1.15 1.30	2.40 2.57	2.49	0.67	0.68
C 1/2035...	353	62	31	53	1	862	862	0.780	0.59	0.46	0.36	1.27	2.68	2.68	0.61	0.63
C 1/35 SP...	417	34	18	30	1	709	709	0.951	0.69	0.25	0.21	0.72	1.87	1.87	0.90	0.90
C 1/2035SP.	393 409	48 31	21 20	38 38	0 2	759 748	753	0.895	0.65 0.68	0.35 0.23	0.24 0.23	0.91 0.91	2.15 2.05	2.10	0.80	0.81
C 2/2035SP.	301 275	68 70	43 50	93 107	-5 -2	1044 1132	1088	0.619	0.50 0.46	0.50 0.52	0.49 0.58	2.23 2.57	3.72 4.13	3.93	0.38	0.43
C 1/38.....	385 420	67 36	22 16	29 25	-3 3	729 693	711	0.948	0.64 0.70	0.49 0.27	0.25 0.18	0.70 0.60	2.08 1.75	1.92	0.90	0.88
C 1/38.....	409 399	37 50	22 21	32 30	0 0	725 727	726	0.930	0.68 0.66	0.27 0.37	0.25 0.24	0.77 0.72	1.97 1.99	1.98	0.86	0.85
C 3/38.....	392 417	52 37	22 17	34 30	0 -1	746 701	724	0.931	0.65 0.69	0.38 0.27	0.25 0.20	0.82 0.72	2.10 1.88	1.99	0.87	0.85
C 3/2038...	382 381	51 55	25 24	44 40	-2 0	787 782	785	0.859	0.63 0.63	0.38 0.40	0.29 0.28	1.06 0.96	2.36 2.27	2.32	0.74	0.73
C 1/37.....	350 328	61 76	31 38	57 60	1 -2	880 911	896	0.752	0.58 0.55	0.45 0.56	0.36 0.44	1.37 1.44	2.76 2.99	2.88	0.57	0.59
C 1/2037...	352 355	61 68	33 31	55 46	-1 0	872 834	853	0.789	0.58 0.59	0.45 0.50	0.38 0.36	1.32 1.10	2.73 2.55	2.64	0.62	0.64
C 1/39.....	399 398	44 40	23 24	35 34	-1 0	741 745	743	0.907	0.66 0.66	0.32 0.29	0.26 0.28	0.84 0.82	2.08 2.05	2.07	0.82	0.82
C 3/39.....	437 415	20 41	18 18	25 28	0 -2	670 695	683	0.987	0.73 0.69	0.15 0.30	0.21 0.21	0.60 0.67	1.69 1.87	1.78	0.97	0.95
C 3/2039...	397 360	42 70	22 25	37 44	2 1	758 819	789	0.857	0.66 0.60	0.31 0.51	0.25 0.29	0.89 1.06	2.11 2.46	2.29	0.73	0.74
C 3/13.....	417 377	25 53	20 25	42 47	-4 -2	734 806	769	0.877	0.69 0.63	0.18 0.39	0.23 0.29	1.01 1.13	2.11 2.44	2.28	0.77	0.74

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			$\sigma_s$	Stadler, standard = 1.69

## SYDNEY COAL-FIELD—Continued

C13/13....	367	55	26	51	1	829	837	0.805	0.61	0.40	0.30	1.22	2.53	2.55	0.65	0.66
	348	78	25	47	2	846			0.58	0.57	0.29	1.13	2.57			
C 3/2013...	341	59	30	69	1	928	889	0.760	0.57	0.43	0.35	1.66	3.01	2.81	0.58	0.60
	372	43	29	56	0	850			0.62	0.32	0.33	1.34	2.61			
C 1/12.....	312	91	39	57	1	926	870	0.774	0.52	0.67	0.45	1.37	3.01	2.74	0.60	0.62
	367	62	26	46	-1	813			0.61	0.46	0.30	1.10	2.47			
C 3/12.....	392	37	23	48	0	796	796	0.848	0.65	0.27	0.26	1.15	2.33	2.33	0.72	0.73
C 3/2012...	245	102	59	94	0	1136	1155	0.584	0.41	0.75	0.68	2.25	4.09	4.15	0.34	0.41
	249	78	71	100	2	1173			0.41	0.57	0.82	2.40	4.20			

## INVERNESS COAL-FIELD.

C 1/15.....	284	66	58	92	0	1090	1090	0.618	0.47	0.49	0.67	2.21	3.84	3.84	0.38	0.44
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## PICTOU COAL-FIELD.

C 1/2004...	251	80	63	106	0	1175	1175	0.575	0.42	0.59	0.72	2.54	4.27	4.27	0.33	0.40
C 1/16.....	428	26	18	25	3	688	679	0.995	0.71	0.19	0.21	0.60	1.71	1.67	0.99	1.01
	425	37	15	20	3	671			0.71	0.27	0.17	0.48	1.63			
C 1/2016...	431	27	18	24	0	673	695	0.970	0.72	0.20	0.21	0.58	1.71	1.84	0.94	0.92
	400	47	29	26	-2	717			0.66	0.35	0.33	0.62	1.96			
C 1/1.....	301	73	46	81	-1	1020	1020	0.661	0.50	0.54	0.53	1.94	3.51	3.51	0.44	0.48
C 1/2002...	408	47	17	28	0	706	673	1.000	0.68	0.35	0.20	0.67	1.90	1.70	1.00	0.99
	447	19	12	20	2	640			0.74	0.14	0.14	0.48	1.50			
C 1/8.....	442	27	12	17	2	635	639	1.054	0.73	0.20	0.14	0.41	1.48	1.51	1.11	1.12
	433	34	16	16	1	643			0.72	0.25	0.18	0.38	1.53			
C 1/2008...	450	21	12	17	0	620	669	1.008	0.75	0.15	0.14	0.41	1.45	1.70	1.02	0.99
	400	51	22	27	0	717			0.66	0.38	0.25	0.65	1.94			
C 2/2008...	387	40	27	44	2	799	799	0.845	0.64	0.29	0.31	1.06	2.30	2.30	0.71	0.74
C 1/3.....	375	69	23	32	1	764	744	0.906	0.62	0.51	0.26	0.77	2.16	2.04	0.82	0.83
	420	23	22	33	2	724			0.70	0.17	0.25	0.79	1.91			
C 1/2003...	408	41	21	28	2	718	700	0.961	0.68	0.30	0.24	0.67	1.89	1.75	0.92	0.97
	437	19	14	24	6	681			0.73	0.14	0.16	0.58	1.61			

TABLE VI—Continued.

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material.				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			$\frac{S}{100}$	Stadler, standard = 1.69
SPRINGHILL COAL-FIELD.																
C 1/49.....	417 433	43 24	21 19	21 21	-2 3	671 671	671	1.005	0.69 0.72	0.32 0.18	0.24 0.22	0.50 0.50	1.75 1.62	1.69	1.01	1.00
C 1/5.....	383 381	66 58	25 23	34 38	-8 0	735 774	754	0.895	0.64 0.63	0.49 0.43	0.29 0.26	0.82 0.91	2.24 2.23	2.24	0.80	0.75
C 1/2005...	411 383	41 65	20 20	26 29	2 3	707 749	728	0.926	0.68 0.64	0.30 0.48	0.23 0.23	0.62 0.70	1.83 2.05	1.94	0.86	0.87
C 1/6.....	380 394	47 41	31 24	43 43	-1 -2	798 772	785	0.857	0.63 0.65	0.35 0.30	0.36 0.28	1.03 1.03	2.37 2.26	2.32	0.73	0.73
C 1/2006...	410 425	43 31	21 18	26 27	0 -1	703 685	694	0.971	0.68 0.71	0.32 0.23	0.24 0.21	0.62 0.65	1.86 1.80	1.83	0.94	0.92
JOGGINS-CHIGNECTO COAL-FIELD.																
C 1/7.....	350	55	33	56	6	896	896	0.753	0.58	0.40	0.38	1.34	2.70	2.70	0.57	0.63
C 1/9.....	285	79	45	91	0	1069	1069	0.629	0.47	0.58	0.52	2.18	3.75	3.75	0.40	0.45
C 3/10.....	334	51	36	74	5	972	972	0.691	0.55	0.38	0.41	1.77	3.11	3.11	0.48	0.54
C 3/3010...	385	57	24	34	0	758	758	0.889	0.64	0.42	0.28	0.82	2.16	2.16	0.79	0.78
FRANK COAL-FIELD.																
C 1/48.....	287 305	80 82	50 44	83 70	0 -1	1047 978	1013	0.668	0.48 0.51	0.59 0.60	0.58 0.51	1.99 1.68	3.64 3.30	3.47	0.45	0.49
C 3/48.....	293 315	91 57	44 47	69 84	3 -3	1000 1010	1005	0.670	0.49 0.52	0.67 0.42	0.51 0.54	1.65 2.02	3.32 3.50	3.41	0.45	0.50
C 4/2048...	260 287	94 72	50 46	97 95	-1 0	1120 1085	1102	0.612	0.43 0.48	0.69 0.53	0.58 0.53	2.33 2.28	4.03 3.82	3.93	0.37	0.43
C 1/32.....	321 307	72 89	36 38	70 62	1 4	956 959	958	0.705	0.53 0.51	0.53 0.66	0.41 0.44	1.68 1.49	3.15 3.10	3.13	0.50	0.54
C 3/32.....	317 289	67 94	47 43	75 76	-6 -2	969 1009	989	0.681	0.53 0.48	0.49 0.69	0.54 0.50	1.80 1.82	3.36 3.49	3.43	0.46	0.49
C 4/2032...	304 296 352	92 101 43	36 40 37	68 65 70	0 -2 -2	966 962 919	949	0.710	0.50 0.49 0.58	0.68 0.74 0.32	0.41 0.46 0.43	1.63 1.56 1.68	3.22 3.25 3.01	3.16	0.50	0.54
C 5/2032...	336 304 340	71 75 55	37 49 41	57 72 70	-1 0 -6	895 995 922	937	0.720	0.56 0.50 0.56	0.52 0.55 0.40	0.43 0.56 0.47	1.37 1.73 1.68	2.88 3.34 3.11	3.11	0.52	0.54

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material.				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			$\frac{S}{S_s}$	Stadler, standard = 1.69
FRANK COAL-FIELD—Continued.																
C 1/33.....	388 381	51 45	23 28	38 46	0 0	767 807	787	0.857	0.64 0.63	0.38 0.33	0.26 0.32	0.91 1.10	2.19 2.38	2.29	0.73	0.74
C 3/33.....	333 343	78 48	31 42	59 68	-1 -1	897 930	914	0.738	0.55 0.57	0.57 0.35	0.36 0.48	1.42 1.63	2.90 3.03	2.97	0.54	0.57
C 4/2033...	378 319 355 368	49 74 61 49	25 42 29 29	48 66 56 55	0 -1 -1 -1	810 948 862 845	839	0.803	0.63 0.53 0.59 0.61	0.36 0.54 0.45 0.36	0.29 0.48 0.33 0.33	1.15 1.58 1.34 1.32	2.43 3.13 2.71 2.62	2.72	0.64	0.62
C 1/28.....	306 279	64 97	46 47	82 75	2 2	1028 1033	1031	0.653	0.51 0.46	0.47 0.71	0.53 0.54	1.97 1.80	3.48 3.51	3.50	0.43	0.48
C 2/28.....	218 250	110 75	63 54	112 122	-3 -1	1218 1214	1216	0.554	0.36 0.41	0.81 0.55	0.72 0.62	2.69 2.93	4.58 4.51	4.55	0.31	0.37
C 3/28.....	316 308	73 69	39 40	70 80	2 3	971 1016	994	0.679	0.52 0.51	0.54 0.51	0.45 0.46	1.68 1.92	3.19 3.40	3.30	0.46	0.51
C 4/2028...	329 349 293 296	67 65 95 77	37 31 46 49	68 56 66 78	-1 -1 0 0	936 870 980 1020	951	0.709	0.55 0.58 0.49 0.49	0.49 0.48 0.70 0.57	0.43 0.36 0.53 0.56	1.63 1.34 1.58 1.87	3.10 2.76 3.30 3.49	3.16	0.50	0.53
C 1/34.....	351 332	56 78	37 34	59 52	-3 4	880 896	888	0.761	0.58 0.55	0.41 0.57	0.43 0.39	1.42 1.25	2.84 2.76	2.80	0.58	0.60
C 2/34.....	146	83	77	193	1	1593	1593	0.423	0.24	0.61	0.89	4.63	6.37	6.37	0.18	0.27
C 4/2034...	274 286 210 256	82 73 127 100	55 49 60 54	88 90 103 88	1 2 0 2	1086 1077 1205 1106	1090	0.619	0.45 0.47 0.35 0.42	0.60 0.54 0.93 0.74	0.63 0.56 0.69 0.62	2.11 2.16 2.47 2.11	3.79 3.73 4.44 4.09	4.01	0.38	0.42
C 1/34 SP..	389 362	39 63	27 28	43 45	2 2	792 827	810	0.832	0.65 0.60	0.29 0.46	0.31 0.32	1.03 1.08	2.28 2.46	2.37	0.69	0.71
C 4/2034 SP	266 251	84 102	53 57	98 91	-1 -1	1118 1114	1116	0.604	0.44 0.42	0.62 0.75	0.61 0.66	2.35 2.18	4.02 4.01	4.02	0.36	0.42
C 5/2034 SP	325 337 346	75 70 60	42 38 37	57 54 57	1 1 0	918 892 888	900	0.749	0.54 0.56 0.57	0.55 0.51 0.44	0.48 0.44 0.43	1.37 1.29 1.37	2.94 2.80 2.81	2.85	0.56	0.59
CROWSNEST COAL-FIELD.																
C 1/31.....	447 429	15 34	15 14	24 23	-1 0	649 666	658	1.023	0.74 0.71	0.11 0.25	0.17 0.16	0.58 0.55	1.60 1.67	1.64	1.05	1.03
C 2/31.....	336 322	54 69	40 40	69 69	1 0	945 956	951	0.709	0.56 0.53	0.40 0.51	0.46 0.46	1.65 1.65	3.07 3.15	3.11	0.50	0.54

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			$\mathcal{S}_2$	Stadler, standard = 1.69
CROWSNEST COAL-FIELD—Continued.																
C 4/2031...	364 391 375	71 43 72	26 26 24	39 41 32	0 —0 —3	797 774 750			0.60 0.65 0.62	0.52 0.32 0.58	0.30 0.30 0.28	0.94 0.98 0.77	2.46 2.25 2.20	2.30	0.76	0.73
C 1/30.....	357	50	35	57	1	878	878	0.768	0.59	0.37	0.40	1.37	2.73	2.73	0.59	0.62
C 1/29.....	367 425	67 31	25 12	42 32	—1 0	798 694	746	0.904	0.61 0.71	0.49 0.23	0.29 0.14	1.01 0.77	2.40 1.85	2.13	0.82	0.79
C 3/29.....	406 407	20 37	24 21	41 37	9 —2	790 736	763	0.883	0.67 0.68	0.15 0.27	0.28 0.24	0.98 0.89	2.08 2.08	2.08	0.78	0.81
C 4/2029...	406 387	52 49	18 29	24 35	0 0	695 764	730	0.922	0.67 0.64	0.38 0.36	0.21 0.33	0.58 0.84	1.84 2.17	2.01	0.85	0.84
C 4/51.....	195 187 169 227	100 94 113 96	74 74 71 53	133 146 147 124	—2 —1 0 0	1326 1381 1406 1246	1318	0.514	0.32 0.31 0.28 0.38	0.74 0.69 0.83 0.71	0.85 0.85 0.82 0.61	3.19 3.50 3.52 2.97	5.10 5.35 5.45 4.67	5.14	0.26	0.33
C 4/52.....	369 392	65 43	25 24	41 42	0 —1	796 772	784	0.859	0.61 0.65	0.48 0.32	0.29 0.28	0.98 1.01	2.36 2.26	2.31	0.74	0.73
C 5/52.....	423 398 400	30 43 44	17 23 22	32 36 34	—2 0 0	696 749 738	728	0.927	0.70 0.66 0.66	0.22 0.32 0.32	0.20 0.26 0.25	0.77 0.86 0.82	1.89 2.10 2.05	2.01	0.86	0.84
C 4/53.....	389 380	43 48	22 25	45 46	1 1	789 805	797	0.848	0.65 0.63	0.32 0.35	0.25 0.29	1.08 1.10	2.30 2.37	2.34	0.72	0.72
C 1/27.....	426 436	35 27	13 14	28 28	—2 —5	678 659	669	1.008	0.71 0.72	0.26 0.20	0.15 0.16	0.67 0.67	1.79 1.75	1.77	1.02	0.96
C 4/2027...	380 403	48 31	29 25	43 40	0 1	797 762	780	0.862	0.63 0.67	0.35 0.23	0.33 0.29	1.03 0.96	2.34 2.15	2.25	0.74	0.75
C 1/26.....	361 414	61 27	32 25	46 31	0 3	831 730	781	0.863	0.60 0.69	0.45 0.20	0.37 0.29	1.10 0.74	2.52 1.92	2.22	0.74	0.76
C 2/26.....	332 310	53 67	41 40	74 82	0 1	963 1014	989	0.681	0.55 0.51	0.39 0.49	0.47 0.46	1.78 1.97	3.19 3.43	3.31	0.46	0.51
C 3/26.....	423 397	26 50	17 22	32 31	2 0	711 733	722	0.934	0.70 0.66	0.19 0.37	0.20 0.25	0.77 0.74	1.86 2.02	1.94	0.87	0.87
C 4/2026...	395 387 400	51 49 35	23 28 27	32 36 39	—1 0 —1	735 766 757	753	0.892	0.66 0.64 0.66	0.38 0.36 0.26	0.26 0.32 0.31	0.77 0.86 0.94	2.07 2.18 2.17	2.14	0.80	0.79
C 5/2026...	413 399 410	34 49 38	22 22 20	31 32 32	0 —2 0	715 728 720	721	0.935	0.69 0.66 0.68	0.25 0.36 0.28	0.25 0.25 0.23	0.74 0.77 0.77	1.93 2.04 1.96	1.98	0.87	0.85

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			¢	Stadler, standard = 1.69
SIMILKAMEEN COAL-FIELD.																
C 1/Ex. 2...	410	31	24	35	0	735	735	0.919	0.68	0.23	0.28	0.84	2.03	2.03	0.84	0.83
C 1/Ex. 202	428	27	18	27	0	683	693	0.970	0.71	0.20	0.21	0.65	1.77	1.80	0.94	0.94
	420	31	20	28	1	702			0.70	0.23	0.23	0.67	1.83			
C 1/Ex. 3...	292	94	50	62	2	981	981	0.687	0.48	0.69	0.58	1.49	3.24	3.24	0.47	0.52
NICOLA VALLEY COAL-FIELD.																
C 1, 22SP...	275	93	51	81	0	1055	1055	0.639	0.46	0.68	0.59	1.94	3.67	3.67	0.41	0.46
NANAIMO COAL-FIELD.																
C 1/20.....	367	62	27	43	1	812	819	0.822	0.61	0.46	0.31	1.03	2.41	2.44	0.68	0.69
	369	52	33	46	0	825			0.61	0.38	0.38	1.10	2.47			
C 4/2020...	370	63	23	44	0	803	781	0.863	0.61	0.46	0.26	1.06	2.39	2.28	0.74	0.74
	384	56	21	39	0	770			0.64	0.41	0.24	0.94	2.23			
	376	57	27	40	0	788			0.62	0.42	0.31	0.96	2.31			
	376	58	27	39	0	785			0.62	0.43	0.31	0.94	2.30			
	385	49	24	42	0	783			0.64	0.36	0.28	1.01	2.29			
	398	43	21	38	0	752			0.66	0.32	0.24	0.91	2.13			
C 5/2020...	384	60	25	32	-1	748	774	0.871	0.64	0.44	0.29	0.77	2.14	2.22	0.76	0.74
	389	54	20	39	-2	758			0.65	0.40	0.23	0.94	2.22			
	358	72	28	44	-2	815			0.60	0.53	0.32	1.06	2.51			
C 1/18.....																
C 4/2018...	296	62	44	97	1	1080	1031	0.654	0.49	0.46	0.51	2.33	3.79	3.40	0.43	0.50
	283	86	47	84	0	1050			0.47	0.63	0.54	2.02	3.66			
	306	83	46	65	0	964			0.51	0.61	0.53	1.56	3.21			
	347	55	34	65	-1	905			0.58	0.40	0.39	1.56	2.93			
C 1/17.....	184	109	84	127	-4	1323	1323	0.508	0.31	0.80	0.97	3.05	5.13	5.13	0.26	0.33
C 1/21.....	366	64	26	45	-1	812	809	0.833	0.61	0.47	0.30	1.08	2.46	2.43	0.69	0.70
	382	44	28	47	-1	805			0.63	0.32	0.32	1.13	2.40			
C 1/21M...	391	38	31	42	-2	780	793	0.849	0.65	0.28	0.36	1.01	2.30	2.39	0.72	0.71
	367	65	26	45	-3	805			0.61	0.48	0.30	1.08	2.47			
C 3/21M...	411	34	19	36	0	733	733	0.919	0.68	0.25	0.22	0.86	2.01	2.01	0.84	0.84

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			$\zeta_s$	Stadler, standard = 1.69
WHITEHORSE COAL-FIELD.																
C 1/Ex. 31.	339 365	57 51	36 24	67 58	1 2	930 864	897	0.751	0.56 0.61	0.42 0.38	0.41 0.28	1.61 1.39	3.00 2.66	2.83	0.56	0.60
C 1/Ex. 231	394 407	50 40	23 21	34 31	-1 1	745 726	736	0.918	0.65 0.68	0.37 0.29	0.26 0.24	0.82 0.74	2.10 1.95	2.03	0.84	0.83
C 1/Ex. 32.	304	76	44	73	3	1002	1002	0.672	0.50	0.56	0.51	1.75	3.32	3.32	0.45	0.51
C 1/Ex. 232	364 315	45 80	40 45	54 61	-3 -1	852 939	896	0.751	0.60 0.52	0.33 0.59	0.46 0.52	1.29 1.46	2.68 3.09	2.89	0.56	0.59
C 1/Ex. 33.	385 370	51 69	27 28	37 35	0 -2	769 773	771	0.872	0.64 0.61	0.38 0.51	0.31 0.32	0.89 0.84	2.22 2.28	2.25	0.76	0.75
C 1/Ex. 233	404 430	44 32	27 16	24 21	1 1	713 662	688	0.980	0.67 0.71	0.32 0.24	0.31 0.18	0.58 0.50	1.88 1.63	1.76	0.96	0.96

## SPECIAL COKES.

C 1.....	416	33	16	34	1	721	721	0.934	0.69	0.24	0.18	0.82	1.93	1.93	0.87	0.88
C 4.....	408 435	50 25	16 16	26 23	0 1	699 655	682	0.989	0.68 0.72	0.37 0.18	0.18 0.18	0.62 0.55	1.85 1.63	1.74	0.98	0.97
C 5.....	429 387	26 52	17 22	29 40	-1 -1	683 768	726	0.930	0.71 0.64	0.19 0.38	0.20 0.25	0.70 0.96	1.80 2.23	2.02	0.87	0.84
C 6.....	434 425	26 29	15 18	25 28	0 0	669 691	680	0.991	0.72 0.71	0.19 0.21	0.17 0.21	0.60 0.67	1.68 1.80	1.74	0.98	0.97
C 7.....	404 411	40 37	18 21	27 30	11 1	745 718	732	0.920	0.67 0.68	0.29 0.27	0.21 0.24	0.65 0.72	1.82 1.91	1.87	0.85	0.90
C 8.....	406 433	39 24	20 13	38 26	-3 4	736 684	710	0.949	0.67 0.72	0.29 0.18	0.23 0.15	0.91 0.62	2.10 1.67	1.89	0.90	0.89
C 9.....	381 410	60 32	24 18	36 39	-1 1	764 746	755	0.893	0.63 0.68	0.44 0.24	0.28 0.21	0.86 0.94	2.21 2.07	2.14	0.80	0.79
C 10.....	399	33	21	46	1	781	781	0.861	0.66	0.24	0.24	1.10	2.24	2.24	0.74	0.75
C 11.....	367 416	71 31	26 23	39 31	-3 -1	783 710	747	0.903	0.61 0.69	0.52 0.23	0.30 0.20	0.94 0.74	2.37 1.92	2.15	0.82	0.79
C 12.....	431 398	30 58	14 17	25 32	0 -5	671 713	692	0.974	0.72 0.66	0.22 0.43	0.10 0.20	0.60 0.77	1.70 2.06	1.88	0.95	0.90
C 13.....	409 432	36 26	24 15	31 27	0 0	724 677	701	0.961	0.68 0.72	0.27 0.19	0.28 0.17	0.74 0.65	1.97 1.73	1.85	0.92	0.91

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			Q	Stadler, standard = 1.69
SPECIAL COKES—Continued																
C 14.....	431 400	29 48	16 20	27 32	-3 0	669 732	701	0.961	0.72 0.66	0.21 0.35	0.18 0.23	0.65 0.77	1.76 2.01	1.89	0.92	0.89
C 15.....	395 397	44 44	21 20	37 40	3 -1	762 756	759	0.888	0.66 0.66	0.32 0.32	0.24 0.23	0.89 0.96	2.11 2.17	2.14	0.79	0.79
C 16.....	419 420	37 33	20 17	25 30	-1 0	684 701	693	0.973	0.70 0.70	0.27 0.24	0.23 0.20	0.60 0.72	1.80 1.86	1.83	0.95	0.92
C 81.....	303	67	43	88	-1	1039	1039	0.649	0.50	0.49	0.50	2.11	3.60	3.60	0.42	0.47
C 82.....	324	60	33	84	-1	993	993	0.679	0.54	0.44	0.38	2.01	3.37	3.37	0.46	0.50
C 83.....	362 332	54 66	30 34	56 66	-2 2	852 936	894	0.754	0.60 0.55	0.40 0.49	0.35 0.39	1.34 1.58	2.69 3.01	2.85	0.57	0.59
C 86.....	426	23	17	36	-2	708	708	0.952	0.71	0.17	0.20	0.86	1.94	1.94	0.91	0.87
C 87.....	360	52	31	53	4	865	865	0.780	0.60	0.38	0.36	1.27	2.61	2.61	0.61	0.65
C 88.....	399 413	52 32	19 20	31 37	-1 -2	725 729	727	0.928	0.66 0.69	0.38 0.24	0.22 0.23	0.74 0.89	2.00 2.05	2.03	0.86	0.83
C 89.....	402 336	40 89	22 32	37 49	-1 -6	745 846	796	0.847	0.67 0.56	0.29 0.65	0.25 0.37	0.89 1.18	2.10 2.76	2.43	0.72	0.70
C 97.....	378 394	57 39	22 23	43 44	0 0	790 778	784	0.860	0.63 0.65	0.42 0.29	0.25 0.26	1.03 1.06	2.33 2.26	2.30	0.74	0.73
C 98.....	380	64	27	50	-1	836	836	0.807	0.63	0.47	0.31	1.20	2.61	2.61	0.65	0.65
C 113.....	427 429 426	35 36 39	20 18 21	17 17 16	1 0 -2	656 649 645	650	1.037	0.71 0.71 0.71	0.26 0.27 0.29	0.23 0.21 0.24	0.41 0.41 0.38	1.61 1.60 1.62	1.61	1.08	1.05
C 114.....	438 426 426	29 38 36	17 16 17	17 21 22	-1 -1 -1	635 660 664	654	1.030	0.73 0.71 0.71	0.21 0.28 0.27	0.20 0.18 0.20	0.41 0.50 0.53	1.55 1.67 1.71	1.64	1.06	1.03
C 115.....	430 420 417	25 26 37	17 17 14	31 39 35	-3 -2 -3	684 724 709	706	0.954	0.71 0.70 0.69	0.18 0.19 0.27	0.20 0.20 0.16	0.74 0.94 0.84	1.83 2.03 1.96	1.94	0.91	0.87
C 116.....	432 422 426	25 30 42	18 20 11	24 28 21	-1 0 0	671 696 656	674	1.000	0.72 0.70 0.71	0.18 0.22 0.31	0.21 0.23 0.13	0.58 0.67 0.50	1.69 1.82 1.65	1.72	1.00	0.98
C 117.....	337 325 338	48 51 47	35 43 35	82 79 79	-2 2 1	971 996 970	979	0.689	0.56 0.54 0.56	0.35 0.38 0.35	0.40 0.50 0.40	1.97 1.89 1.89	3.28 3.31 3.20	3.26	0.47	0.52
C 118.....	362 316 367	47 87 37	25 29 25	65 72 69	1 -4 2	888 945 899	911	0.740	0.60 0.52 0.61	0.35 0.64 0.27	0.29 0.33 0.29	1.56 1.73 1.65	2.80 3.22 2.82	2.95	0.55	0.57

TABLE VI—Continued

Coke Number	Weight on $\frac{1}{2}$ " = grams	Weight on $\frac{5}{16}$ " = grams	Weight on $\frac{3}{16}$ " = grams	Weight through $\frac{3}{16}$ " = grams	Weight lost grams	Factor	Mean factor	Relative strength S	Stadler's values for material				Stadler's energy units, total	Mean total	Relative strength values.	
									On $\frac{1}{2}$ "	On $\frac{5}{16}$ "	On $\frac{3}{16}$ "	Through $\frac{3}{16}$ "			$\tau_s$	Stadler, standard = 1.69

SPECIAL COKES—Continued

C 119.....	421	33	18	28	0	695			0.70	0.24	0.21	0.67	1.82			
	428	26	16	32	-2	691	688	0.980	0.71	0.19	0.18	0.77	1.85	1.81	0.96	0.93
	424	37	13	27	-1	679			0.70	0.27	0.15	0.65	1.77			
C 120.....	334	89	30	49	-2	857			0.55	0.65	0.35	1.18	2.73			
	338	76	36	51	-1	870	864	0.780	0.56	0.56	0.41	1.22	2.75	2.74	0.61	0.62
C 121.....	347	67	31	51	4	872			0.58	0.49	0.36	1.22	2.65			
	370	55	22	51	2	831	852	0.791	0.61	0.40	0.25	1.22	2.48	2.57	0.63	0.66
C 122.....	327	74	37	63	-1	918			0.54	0.54	0.43	1.51	3.02			
	349	51	39	62	-1	899	925	0.729	0.58	0.38	0.45	1.49	2.90	3.05	0.53	0.55
	330	57	40	75	-2	959			0.55	0.42	0.46	1.80	3.23			
C 123.....	365	64	28	45	-2	811			0.61	0.47	0.32	1.08	2.48			
	350	77	30	44	-1	828	811	0.830	0.58	0.57	0.35	1.06	2.56	2.45	0.69	0.69
	381	48	28	42	1	795			0.63	0.35	0.32	1.01	2.31			
C 35D.....	409	37	20	35	-1	729	729	0.925	0.68	0.27	0.23	0.84	2.02	2.02	0.86	0.84
C 1/23M + 31.....	296	79	43	83	-1	1032			0.49	0.58	0.50	1.99	3.56			
	308	68	42	80	2	1015	1024	0.659	0.51	0.50	0.48	1.92	3.41	3.49	0.43	0.48
C 1/23M + 26.....	260	75	43	121	1	1195			0.43	0.55	0.50	2.90	4.38			
	268	86	44	103	-1	1122	1159	0.582	0.44	0.63	0.51	2.47	4.05	4.22	0.34	0.40
C 1/23M + D.I.&S.Co.	242	87	55	115	1	1209	1209	0.558	0.40	0.64	0.63	2.76	4.43	4.43	0.31	0.38
C 1/25 + 20.	296	73	46	82	3	1042	1042	0.645	0.49	0.54	0.53	1.97	3.53	3.53	0.42	0.48
C1/40A + 31	324	47	39	90	0	1023	1023	0.659	0.54	0.35	0.45	2.16	3.50	3.50	0.43	0.48



APPENDIX V

WORK OF THE CHEMICAL LABORATORY

BY

EDGAR STANSFIELD



## APPENDIX V

## WORK OF THE CHEMICAL LABORATORY

BY

EDGAR STANSFIELD

*Average Analyses of Regular Coal Samples in Coal Fields Investigated.*

In order to show clearly the type of coal to be found in each of the coal fields investigated, Table VII has been compiled showing the average analysis for each field. Only the regular samples were included in the averages; to have done otherwise would have given undue weight to those seams or collieries from which more than one sample was obtained; the figures for moisture were, however, taken from the mine moisture sample.

*Coal Classifications.*

In Tables VIII, IX, and X are given, for all the regular coals tested, the values calculated for some of the better known coal classification ratios, together with the determined calorific value of the dry coal.

The first column gives the reference number of the coal.

The second column gives the calorific value of the dry coal in calories per gram, as determined by means of the F. Köhler bomb calorimeter.

The third column gives the carbon-hydrogen ratio in the dry coal, calculated from the ultimate analysis of the coal, which was made upon the dry sample.

The fourth column gives the carbon-hydrogen ratio in air dry coal; this is calculated from the ultimate analysis of the dry coal, allowing for the hydrogen and oxygen in the moisture contained in the air dry coal (this moisture determination was made on the mine moisture sample). M. R. Campbell<sup>1</sup> recommends the carbon-hydrogen ratio as the most satisfactory basis for the classification of coals. His analyses were made on air dry samples, while those of this report were made on dry samples. These tables show the amount of difference caused in the ratio.

The fifth column gives the well-known fuel ratio, that is, fixed carbon divided by volatile matter. This is a classification depending on the proximate analysis of the coal; it obviously is not affected by the moisture content of the sample.

The sixth column gives a ratio suggested by D. B. Dowling.<sup>2</sup> This ratio is fixed carbon plus one-half the volatile matter, divided by moisture plus one-half the volatile matter, the analyses being made on the air dry

<sup>1</sup> U.S. Geol. Survey, Prof. Paper 48 (1906), pp. 156-173.

<sup>2</sup> Report No. 1035 of the Geol. Survey Branch of the Department of Mines, Canada, p. 43. See also Canadian Mining Journal, Vol. XXIX, p. 143, 1908.

sample. Actually the analyses were made on the dry sample and calculated to air dry by allowing for the moisture found in the air dry, mine moisture sample.

The seventh column (omitted in Table X) gives the ratio of carbon divided by oxygen plus ash; this is a ratio employed by D. White.<sup>1</sup> It is worth noting that although, as has been discussed elsewhere, the oxygen and ash of a coal analysis are conventional terms, only approximating to definite constituents of the original coal, yet oxygen plus ash has a very definite value and significance, if it is regarded as that part of the coal which is not carbon, hydrogen, nitrogen, or sulphur.

In Table VIII the coals are arranged in geographical order and subdivided into the different coal fields. In Table IX the coals are arranged in order of the calorific values; for comparison with the split volatile ratio it would probably have been better to recalculate the calorific value to the air dry basis. In Table X the coals are arranged in order of the carbon-hydrogen ratio of the dry coal.

TABLE VIII  
COAL CLASSIFICATIONS

Coals arranged in geographical order

Coal-field.	Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split volatile ratio.	C/O+ Ash.
Sydney, N.S. ....	36	7700	15.3	14.5	1.58	3.6	5.4
	35	7780	14.8	14.3	1.44	3.6	6.1
	35 SP.	7800	14.8	14.3	1.70	4.0	6.1
	38	7780	15.4	14.8	1.74	4.0	6.1
	37	7290	14.9	14.3	1.53	3.6	4.0
	39	7660	14.9	13.8	1.55	3.4	5.6
	13	7650	14.8	14.0	1.48	3.5	4.9
	12	7600	14.7	13.5	1.39	3.1	4.7
Inverness, N.S. ....	14	6750	14.0	11.8	1.24	2.5	3.2
	15	6540	15.1	13.9	1.30	3.1	2.7
Pictou, N.S. ....	4	6680	16.2	15.3	1.57	3.7	2.7
	16	7350	16.1	15.4	1.66	3.9	3.9
	1	6990	15.8	.....	1.86	.....	3.4
	2	7320	16.5	15.8	1.85	4.2	4.1
	8	7700	16.5	15.9	2.49	5.3	5.1
	3	7200	16.9	16.4	2.46	5.4	3.9
Springhill, N.S. ....	5	7430	15.3	14.7	1.81	4.1	4.4
	6	7220	15.9	15.0	1.64	3.8	3.9
	49	7880	16.0	.....	1.90	.....	7.8
Joggins-Chignecto, N.S.	7	6750	13.8	12.8	1.11	2.8	3.1
	9	6570	14.7	13.7	1.37	3.2	2.8
	10	6440	15.5	15.2	1.22	3.3	2.5
Grand Lake, N.B. ....	11	7160	15.3	15.0	1.66	4.1	3.8

<sup>1</sup> P. 8, etc., Bulletin 382, U.S. Geol. Survey.

TABLE VIII—Continued

Coal-field.	Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split volatile ratio.	C/O + ash.
Souris, Sask.....	40	5940	12.5	8.2	0.88	1.5	1.8
	41	5360	13.4	8.2	1.08	1.5	1.6
Edmonton, Alta.....	46	5960	14.0	9.0	1.16	1.6	2.0
	42	6060	14.2	9.1	1.36	1.7	2.3
	45	6310	14.6	9.1	1.19	1.6	2.3
Belly river, Alta.....	43	6130	13.7	10.4	1.39	2.2	2.3
	44	6510	13.6	11.4	1.37	2.6	2.5
	47	5450	13.4	12.1	1.33	2.9	1.4
Frank-Blairmore, Alta..	48	6800	15.9	15.7	2.04	4.7	2.9
	32	6920	16.7	16.2	1.89	4.4	3.0
	33	6880	16.6	16.6	2.06	5.1	3.2
	28	6930	16.9	16.6	2.34	5.3	3.1
	34	6510	17.1	16.8	2.19	5.1	2.6
	34 SP.	6960	16.9	16.6	2.51	5.7	3.4
Crowsnest, B.C.....	31	7370	17.5	17.4	2.53	5.9	4.1
	30	7420	17.0	16.8	2.90	6.4	4.4
	29	7490	16.9	16.5	2.72	5.9	4.4
	51	7060	17.7	17.3	2.98	.....	3.7
	52	7270	16.9	16.4	2.42	.....	4.3
	53	7770	15.6	15.2	2.30	.....	6.1
	27	7680	18.0	17.5	2.46	5.4	5.4
	26	7490	17.5	17.3	2.72	6.2	4.6
Cascade, Alta.....	25	7340	19.6	19.1	4.10	8.3	3.9
	23	7400	22.0	21.7	6.44	12.7	5.2
	23 SP.	7040	20.6	20.3	5.68	11.4	4.0
	23 M.	7270	21.3	.....	5.82	.....	4.2
	24	7280	20.6	20.1	4.01	8.2	4.1
Similkameen, B.C.....	Ex. 1	.....	14.9	14.2	1.60	.....	.....
	Ex. 2	.....	15.9	15.4	1.65	.....	.....
	Ex. 3	.....	16.1	14.9	1.61	.....	.....
Nicola valley, B.C. ...	22	6490	13.4	12.3	1.2	2.8	2.6
	22 SP.	6760	13.6	13.0	1.2	3.1	3.0
	22 M.	6510	13.5	.....	1.2	.....	2.5
Nanaimo-Comox, B.C..	20	7310	15.5	15.1	1.2	3.3	3.5
	18	7130	15.0	14.5	1.2	3.1	3.4
	17	6930	15.0	14.3	1.1	3.0	2.9
	21	7150	16.5	.....	1.8	.....	3.5
	21 SP.	7210	16.5	.....	2.1	.....	3.9
	21 M.	7230	16.7	.....	1.9	.....	3.6
Alert bay, B.C. ....	Ex. 34	6170	.....	.....	1.2	.....	.....
Whitehorse, Yukon Territory.....	Ex. 31	6700	17.5	.....	2.3	.....	2.8
	Ex. 32	6310	.....	.....	2.0	.....	.....
	Ex. 33	6790	16.5	.....	2.0	.....	3.0

TABLE IX

## COAL CLASSIFICATIONS

Coals arranged in order of calorific value

Coal No.	C. V.	C/H dry	C/H air dried	Fuel ratio.	Split volatile ratio	C/O + Ash
49	7880	16.0	.....	1.90	.....	7.8
35 SP	7800	14.8	14.3	1.70	4.0	6.1
38	7780	15.4	14.8	1.74	4.0	6.1
35	7780	14.8	14.3	1.44	3.6	6.1
53	7770	15.6	15.2	2.30	.....	6.1
36	7700	15.3	14.5	1.58	3.6	5.4
8	7700	16.5	15.9	2.49	5.3	5.1
27	7680	18.0	17.5	2.46	5.4	5.4
39	7660	14.9	13.8	1.55	3.4	5.6
13	7650	14.8	14.0	1.48	3.5	4.9
12	7600	14.7	13.5	1.39	3.1	4.7
29	7490	16.9	16.5	2.72	5.9	4.4
26	7490	17.5	17.3	2.72	6.2	4.6
5	7430	15.3	14.7	1.81	4.1	4.4
30	7420	17.0	16.8	2.90	6.4	4.4
23	7400	22.0	21.7	6.44	12.7	5.2
31	7370	17.5	17.4	2.53	5.9	4.1
16	7350	16.1	15.4	1.66	3.9	3.9
25	7340	19.6	19.1	4.10	8.3	3.9
2	7320	16.5	15.8	1.85	4.2	4.1
20	7310	15.5	15.1	1.24	3.3	3.5
37	7290	14.9	14.3	1.53	3.6	4.0
24	7280	20.6	20.1	4.01	8.2	4.1
23 M	7270	21.3	.....	5.82	.....	4.2
52	7270	16.9	16.4	2.42	.....	4.3
21 M	7230	16.7	.....	1.91	.....	3.6
6	7220	15.9	15.0	1.64	3.8	3.9
21 SP	7210	16.5	.....	2.14	.....	3.9
3	7200	16.9	16.4	2.46	5.4	3.9
11	7160	15.3	15.0	1.66	4.1	3.8
21	7150	16.5	.....	1.79	.....	3.5
18	7130	15.0	14.5	1.18	3.1	3.4
51	7060	17.7	17.3	2.98	.....	3.7
23 SP	7040	20.6	20.3	5.68	11.4	4.0
1	6990	15.8	.....	1.86	.....	3.4
34 SP	6960	16.9	16.6	2.51	5.7	3.4
28	6930	16.9	16.6	2.34	5.3	3.1
17	6930	15.0	14.3	1.12	3.0	2.9
32	6920	16.7	16.2	1.89	4.4	3.0
33	6880	16.6	16.6	2.06	5.1	3.2
48	6800	15.9	15.7	2.04	4.7	2.9
Ex. 33	6790	16.5	.....	2.02	.....	3.0
22 SP	6760	13.6	13.0	1.23	3.1	3.0
14	6750	14.0	11.8	1.24	2.5	3.2
7	6750	13.8	12.8	1.11	2.8	3.1
Ex. 31	6700	17.5	.....	2.32	.....	2.8
4	6680	16.2	15.3	1.57	3.7	2.7
9	6570	14.7	13.7	1.37	3.2	2.8
15	6540	15.1	13.9	1.30	3.1	2.7
34	6510	17.1	16.8	2.19	5.1	2.6
44	6510	13.6	11.4	1.37	2.6	2.5
22 M	6510	13.5	.....	1.20	.....	2.5
22	6490	13.4	12.3	1.19	2.8	2.6
10	6440	15.5	15.2	1.22	3.3	2.5

TABLE IX—Continued

Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split volatile ratio.	C/O + Ash.
45	6310	14.6	9.0	1.19	1.6	2.3
Ex. 32	6310	.....	.....	2.03	.....	.....
Ex. 34	6170	.....	.....	1.24	.....	.....
43	6130	13.7	10.4	1.39	2.2	2.3
42	6060	14.2	9.1	1.36	1.7	2.3
46	5960	14.0	9.0	1.16	1.6	2.0
40	5940	12.5	8.2	0.88	1.5	1.8
47	5450	13.4	12.1	1.33	2.9	1.4
41	5360	13.4	8.2	1.08	1.5	1.6

TABLE X  
COAL CLASSIFICATIONS

Coals arranged in order of carbon-hydrogen ratio

Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split vola- tile ratio.
23	7400	22.0	21.7	6.44	12.7
23 M	7270	21.3	.....	5.82	.....
23 SP	7040	20.6	20.3	5.68	11.4
24	7280	20.6	20.1	4.01	8.2
25	7340	19.6	19.1	4.10	8.3
27	7680	18.0	17.5	2.46	5.4
51	7060	17.7	17.3	2.98	.....
31	7370	17.5	17.4	2.53	5.9
26	7490	17.5	17.3	2.72	6.2
Ex. 31	6700	17.5	.....	2.32	.....
34	6510	17.1	16.8	2.19	5.1
30	7420	17.0	16.8	2.90	6.4
52	7270	16.9	16.4	2.42	.....
29	7490	16.9	16.5	2.72	5.9
34 SP	6960	16.9	16.6	2.51	5.7
28	6930	16.9	16.6	2.34	5.3
3	7200	16.9	16.4	2.46	5.4
32	6920	16.7	16.2	1.89	4.4
21 M	7230	16.7	.....	1.91	.....
33	6880	16.6	16.6	2.06	5.1
Ex. 33	6790	16.5	.....	2.02	.....
21 SP	7210	16.5	.....	2.14	.....
21	7150	16.5	.....	1.79	.....
8	7700	16.5	15.9	2.49	5.3
2	7320	16.5	15.8	1.85	4.2
4	6680	16.2	15.3	1.57	3.7
16	7350	16.1	15.4	1.66	3.9
Ex. 3	.....	16.1	14.9	1.61	.....
49	7880	16.0	.....	1.90	.....
Ex. 2	.....	15.9	15.4	1.65	.....
48	6800	15.9	15.7	2.04	4.7
6	7220	15.9	15.0	1.64	3.8
1	6990	15.8	.....	1.86	.....
53	7770	15.6	15.2	2.30	.....
20	7310	15.5	15.1	1.24	3.3
10	6440	15.5	15.2	1.22	3.3
38	7780	15.4	14.8	1.74	4.0

TABLE X—Continued

Coal No.	C.V.	C/H dry.	C/H air dried.	Fuel ratio.	Split vola- tile ratio.
11	7160	15.3	15.0	1.66	4.1
5	7430	15.3	14.7	1.81	4.1
36	7700	15.3	14.5	1.58	3.6
15	6540	15.1	13.9	1.30	3.1
18	7130	15.0	14.5	1.18	3.1
17	6930	15.0	14.3	1.12	3.0
39	7660	14.9	13.8	1.55	3.4
37	7290	14.9	14.3	1.53	3.6
Ex. 1	.....	14.9	14.2	1.60	.....
35	7780	14.8	14.3	1.44	3.6
35 SP	7800	14.8	14.3	1.70	4.0
13	7650	14.8	14.0	1.48	3.5
12	7600	14.7	13.5	1.39	3.1
9	6570	14.7	13.7	1.37	3.2
45	6310	14.6	9.0	1.19	1.6
42	6060	14.2	9.1	1.36	1.7
46	5960	14.0	9.0	1.16	1.6
14	6750	14.0	11.8	1.24	2.5
7	6750	13.8	12.8	1.11	2.8
43	6130	13.7	10.4	1.39	2.2
44	6510	13.6	11.4	1.37	2.6
22 SP	6760	13.6	13.0	1.23	3.1
22 M	6510	13.5	.....	1.20	.....
22	6490	13.4	12.3	1.19	2.8
41	5360	13.4	8.2	1.08	1.5
47	5450	13.4	12.1	1.33	2.9
40	5490	12.5	8.2	0.88	1.5

*Comparison of Determined and Calculated Calorific Values.*

In Table XI is given the determined calorific values of all regular coal samples together with the calorific values calculated both from the ultimate and from the proximate analyses of these samples.

The coals are arranged geographically and classified into the different fields; the reference number of the sample is given in the first column.

The second column gives the determined calorific value of the dry coal, expressed in calories per gram.

The third column gives the calorific value calculated from the ultimate analysis by means of Dulong's formula.

$80.8 C + 344.6 (H - \frac{1}{8}O) + 22.5 S = \text{calorific value in calories per gram}$ —where C, H, O, and S stand for the percentages of carbon, hydrogen, oxygen and sulphur, respectively, in the sample.

The fourth column gives the difference between the values in the third column and the determined calorific value. At the foot of the column these differences are averaged in two ways ; firstly, the arithmetic average in which the numbers are considered as such and difference of sign not considered; secondly, the algebraic average in which difference of sign is taken into account.

TABLE XI  
COMPARISON OF DETERMINED AND CALCULATED CALORIFIC  
VALUES

Coal-field.	Coal No.	Deter- mined C.V.	Calc. C.V. by Dulong's formula.	Differ- ence.	Calc. C.V. by Goutal's formula.	Differ- ence.
Sydney, N.S.....	50	7010	7290	+280	7160	+150
	36	7700	7600	-100	7730	+ 30
	35	7780	7830	+ 50	7600	-180
	35 SP.	7800	7920	+120	7960	+160
	38	7780	7850	+ 70	7970	+190
	37	7290	7360	+ 70	7250	- 40
	39	7660	7720	+ 60	7790	+130
	13	7650	7570	- 80	7630	- 20
	12	7600	7450	-150	.....	.....
Inverness, N.S.....	14	6750	6770	+ 20	.....	.....
	15	6540	6390	-150	.....	.....
Pictou, N.S.....	4	6680	6620	- 60	6800	+120
	16	7350	7280	- 70	7420	+ 70
	1	6990	7080	+ 90	7350	+360
	2	7320	7220	-100	7710	+390
	8	7700	7670	- 30	7910	+210
	3	7200	7230	+ 30	7430	+230
Springhill, N.S.....	5	7430	7450	+ 20	7780	+350
	49	7880	8060	+180	8340	+460
	6	7220	7220	0	7370	+150
Joggins-Chignecto, N.S...	7	6750	6810	+ 60	.....	.....
	9	6570	6590	+ 20	.....	.....
	10	6440	6360	- 80	.....	.....
Grand Lake, N.B.....	11	7160	7220	+ 60	7170	+ 10
Souris, Sask.....	40	5940	5400	-540	.....	.....
	41	5360	5290	- 70	.....	.....
Edmonton, Alta.....	46	5960	5820	-140	.....	.....
	42	6060	6110	+ 50	.....	.....
	45	6310	6000	-310	.....	.....
Belly river, Alta.....	43	6130	6280	+150	.....	.....
	44	6510	6430	- 80	.....	.....
	47	5450	5490	+ 40	.....	.....
Frank-Blairmore, Alta....	48	6800	6910	+110	7110	+310
	32	6920	6770	-150	7310	+390
	33	6880	6970	+ 90	7320	+440
	28	6930	6940	+ 10	7250	+320
	34	6510	6650	+140	6950	+440
	34 SP.	6960	7120	+160	7290	+330
Crowsnest, B.C.....	31	7370	7350	- 20	7620	+250
	30	7420	7500	+ 80	7690	+270
	29	7490	7400	- 90	7630	+140
	51	7060	7260	+200	7390	+330
	52	7270	7460	+190	7540	+270
	53	7770	7980	+210	8040	+270
	27	7680	7690	+ 10	7910	+230
	26	7490	7520	+ 30	7770	+280

TABLE XI—Continued

Coal-field.	Coal No.	Deter- mined C.V.	C.V. calc. by Dulong's formula.	Differ- ence.	C.V. calc. by Goutal's formula.	Differ- ence.
Cascade, B.C.....	25	7340	7040	−300	7660	+320
	23	7400	7530	+130	7660	+260
	23 SP	7040	7290	+250	7330	+290
	23 M	7270	7300	+ 30	7490	+220
	24	7280	7280	0	7480	+200
Similkameen, B.C.....	Ex. 1	.....	.....	.....	7260	.....
	Ex. 2	.....	.....	.....	7180	.....
	Ex. 3	.....	.....	.....	6965	.....
Nicola valley, B.C.....	22	6490	6690	+200	.....	.....
	22 SP	6760	6970	+210	.....	.....
	22 M	6510	6500	− 10	.....	.....
Nanaimo-Comox, B.C....	20	7310	7040	−270	.....	.....
	18	7130	7020	−110	.....	.....
	17	6930	6680	−250	.....	.....
	21	7150	7050	−100	7510	+360
	21 SP	7210	7270	+ 60	7650	+440
	21 M	7230	7120	−110	7600	+370
Alert bay, B.C. ....	Ex. 34	6170	.....	.....	.....	.....
Whitehorse, Yukon Ter- ritory.....	Ex. 31	6700	6690	− 10	7200	+ 500
	Ex. 32	6310	.....	.....	7310	+1000
	Ex. 33	6790	6930	+140	7250	+ 460
Average error:—						
Arithmetic.....	.....	.....	.....	+113	.....	+278
Algebraic.....	.....	.....	.....	+ 4	.....	+267

The fifth column gives the calorific values calculated from the proximate analysis by means of Goutal's formula.<sup>1</sup> The percentage of volatile matter is first recalculated to percentage of pure fuel (fixed carbon + volatile matter), then the calorific value calculated by multiplying the percentage of fixed carbon in the fuel by 82 and adding to the result the product obtained by multiplying the percentage of volatile matter *in the fuel* by a factor which varies, as shown below, with the percentage of volatile matter *in the pure fuel*.

% V.M. in pure fuel.....	5	6	7	8	9	10	11	12	13	14
Factor.....	145	142	139	136	133	130	127	124	122	120
% V.M. in pure fuel.....	15	16	17	18	19	20	21	22	23	24
Factor.....	117	115	113	112	110	109	108	107	105	104
% V.M. in pure fuel.....	25	26	27	28	29	30	31	32	33	34
Factor.....	103	102	101	100	99	98	97	97	96	95
% V.M. in pure fuel.....	35	36	37	38	39	40				
Factor.....	94	91	88	85	82	80				

<sup>1</sup> Goutal, Journal für Gasbeleuchtung, 1905, Vol. 48, p. 1007, Abstr. Electrochemical and Metallurgical Industry, 1907, Vol. 5, p. 145.

For example, coal 50 *analysis*, fixed carbon 53.0%, volatile matter 34.7%, ash 12.3%. Volatile matter in pure fuel =  $34.7 \times \frac{100}{53.0 + 34.7} = 39.6$ , therefore the factor for volatile matter is 81, and the calorific value in calories per gram is  $(53.0 \times 82) + (34.7 \times 81) = 4346 + 2811 = 7157$ .

The last column gives the difference between the values in the fifth column and the determined calorific value. Arithmetical and algebraic averages of these differences are given at the foot of the column.

It is impossible to calculate the calorific values of some Canadian coals by this formula, since the volatile matter in many samples is higher than is provided for in Goutal's formula. A satisfactory formula for even roughly approximating the calorific value of a fuel from its proximate analysis would be very useful, but the differences shown by the table for Goutal's formula are discouragingly large, even within the limits which he himself has set.

#### *Variations in Weight of Samples Stored in Closed Cans.*

The sample cans tested were similar to those used throughout the whole investigation for shipping or storing samples; they are described in Vol. II, p. 125.

A sample of coal No. 14, crushed to  $\frac{1}{8}$ " size and air dried, was used for the tests. Can A was weighed empty; filled with the coal and again weighed; the contents of the can were sprinkled with water, the can closed as usual, and weighed for the last time. Sufficient coal to fill can B was spread out on a couple of trays and dried in an oven for several hours and the loss of weight determined; the dry coal was then put into the can which was closed and weighed.

The two cans were placed in their outer cans and set aside, in order to determine how fast, if at all, the damp coal lost moisture and the dry coal gained it. The cans were re-weighed at intervals for nearly four years.

The portion of coal that was dried lost 7 per cent of moisture, that is to say 107.5 grams of the original sample contain 100 grams of dry coal; 1015.5 grams of the original sample had been put into can A and 975.5 grams into can B.

Table XII shows the changes in weight of the contents of the cans, in order to make these clearer the weights have been re-calculated to the basis of 100 grams of dry coal; Fig. 1 shows the same thing in graphic form. It is quite certain from this test that the sample cans do not preserve the moisture in their contents entirely unchanged; it is, however, impossible to say how much moisture was gained or lost as the coal was apparently absorbing oxygen with noteworthy rapidity. This is clearly shown in the curve for the damp coal; this loses weight at first owing to the comparatively rapid loss of moisture, but afterwards it gains in weight and ultimately becomes heavier than at the beginning, a change which can only be explained by assuming the oxidation of the coal; the sample had been crushed to the size used for the test about eight months before.

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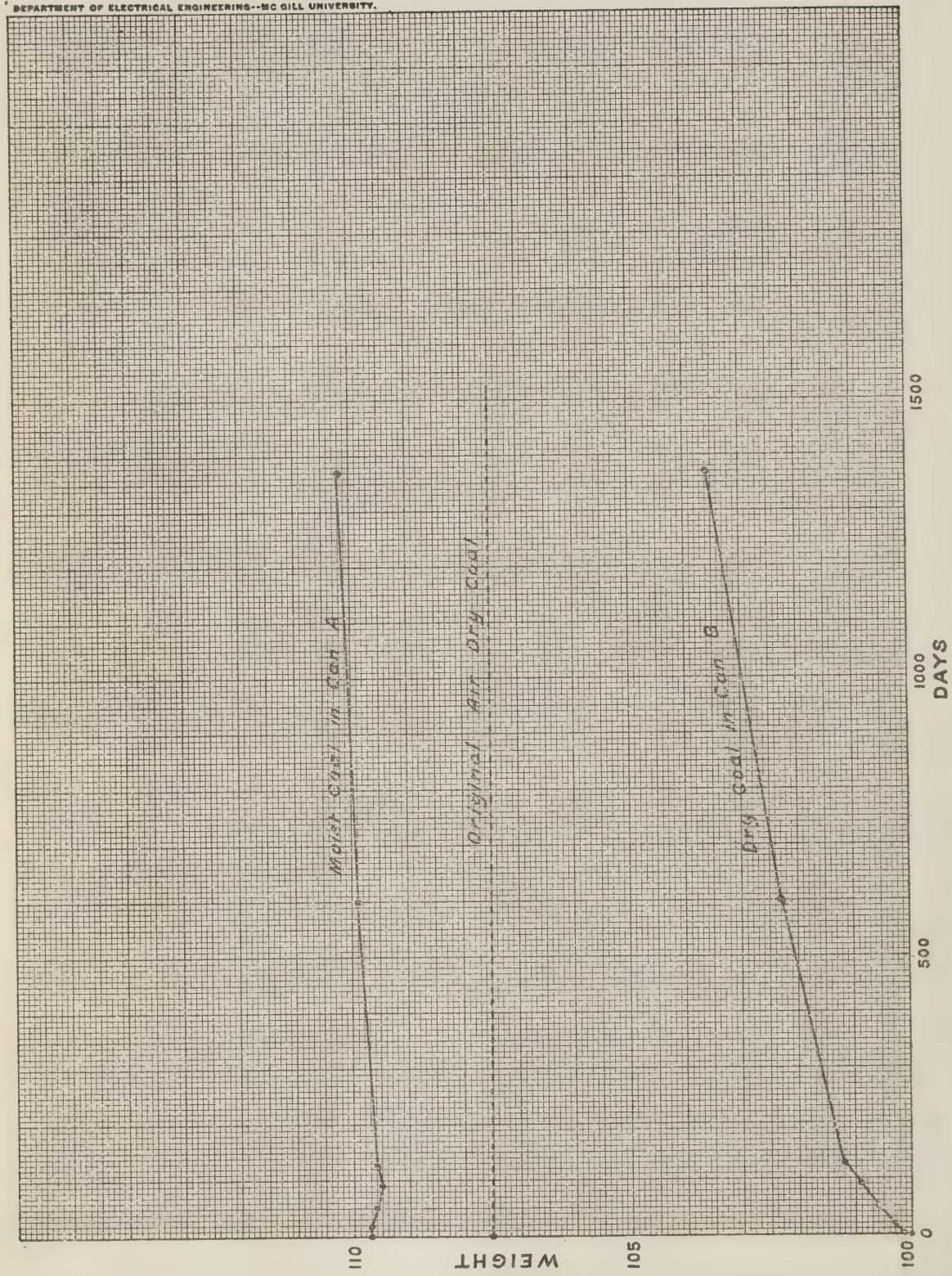


Fig. 1. DIAGRAM SHOWING VARIATIONS IN WEIGHT OF COAL IN CANS

TABLE XII  
VARIATIONS IN WEIGHT OF COAL IN CANS.

	Date	Days elapsed	Moist coal in can A	Dry coal in can B
Air dry coal taken....	1-iv-08.....		107.5	107.5
Coal after moistening .....			109.7	
Coal after drying.....				100.0
Coal stored in can....	1-iv-08.....	0	109.7	
	2-iv-08.....	1		100.1
	16-iv-08.....	15	109.7	100.3
	21-v-08.....	50	109.6	100.6
	30-vi-08.....	90	109.5	100.9
	5-viii-08.....	126	109.6	101.2
	19-xi-09.....	598	109.9	102.3
	30-xii-11.. . . .	1368	110.2	103.6

*Sampling Losses and Coal Dust.*

In order to obtain some idea of the quantity of coal lost as dust or in other ways when a large consignment is sampled, and the possible effect of such loss on the final sample, a careful record was kept whilst two coals were being sampled of the weights of the original consignments and also of all portions cut out; samples of the dust produced whilst sampling one of these coals were also collected and analysed.

The process of sampling has already been described (see Vol. II, p. 123), the dust samples were collected on sheets of paper spread out for the purpose either in the sampling room or outside the building near the orifice of the pipe from the fan used to ventilate the room during the operations of crushing or sampling coal.

Coal No. 35 weighed 9,300 pounds to begin with, it was crushed and sampled down to a sample of about 70 pounds weight which had passed through a  $\frac{1}{4}$ " screen; the total loss in all the stages amounted to 62 pounds.

The final sample contained 5.9 per cent of ash. Dust samples were collected which contained percentages of ash as shown below:—

Taken inside whilst the original coal was passed through a 3" bar screen.....	12.3%
Taken at the same time from near fan orifice outside.....	11.2%
Taken inside under fan hopper during crushing operations.....	11.9%
Taken outside near fan orifice during crushing operations.....	10.5%

Coal No. 36 weighed 8 tons, the total loss during sampling amounted to 104 pounds.

Mr. C. Landry was in charge of the sampling operations and collected the dust samples.

*Hot Air Oven.*

Fig. 2 shows the general construction of the drying oven, a short description of which is given in Part IX, Vol. II, page 132. The figure shows the way in which the products of combustion of the gas used to heat the oven are entirely prevented from entering the oven; it also shows the way in which, by means of double shelves, the heated air rising up through the oven is caused to pass over the surface of any trays placed on the shelves.

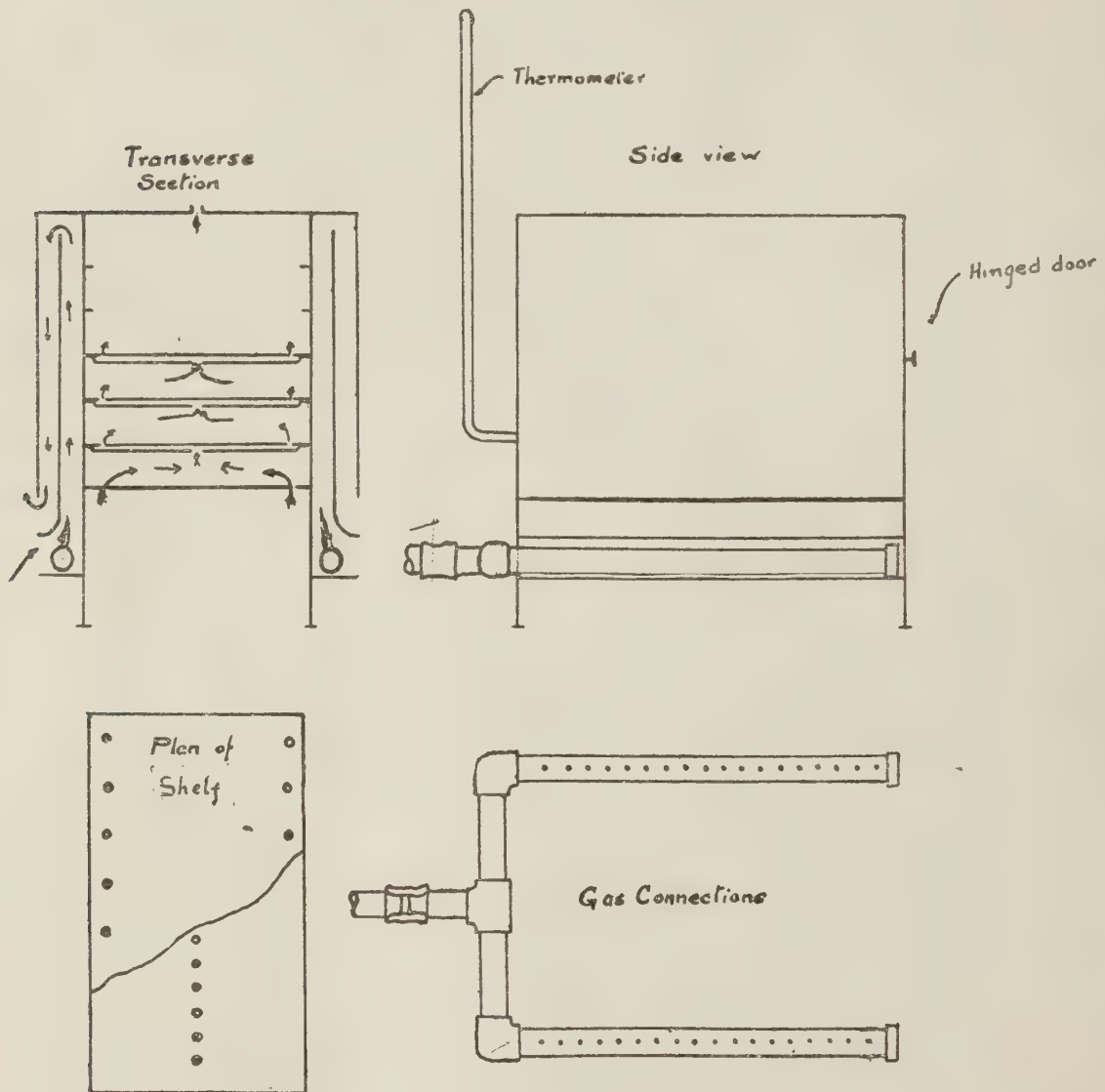
*Hot Air Oven.*

Fig. 2. ILLUSTRATION OF HOT AIR OVEN

*Weathering Tests of Coal*

This subject was not included in the coal tests investigation as originally outlined, but, on account of its importance, an attempt was made to obtain certain information. When a coal seam is first discovered on the

surface, only outcrop samples are as a rule available; it is well known that such samples differ materially from the main body of the seam which has not been exposed to weathering, but the course of such weathering is not sufficiently well known to enable the nature of the unweathered coal to be predicted at all safely from analyses of the weathered coal, and it is this information which is urgently required.

Samples of coals of different degrees of weathering were obtained from six different seams, and a scheme was drawn up according to which the samples were to be tested. The pressure of routine work, however, was too great to allow this scheme to be carried out in its entirety, or with the promptness which is so desirable in work of this nature. The work done was nevertheless considerable, and although it is not sufficiently complete to render it possible or desirable to draw general conclusions at this time, it will doubtless be of value in conjunction with other work that has been, or may be, done on the subject.

The scheme, which was also intended to throw light on the changes which the coal samples undergo when stored in the laboratory, is as follows: the samples are to be weighed as received and re-weighed when the bottles or cans are opened, the contents are to be crushed in a crusher, ground in a ball mill, thoroughly mixed and riffled down, and divided into the following four lots:—

Lot A.—2 large and 10 small sample tubes to be filled full, and 3 small tubes to be one-fourth filled with the raw coal; these tubes to be labelled Ex. . . . (raw), where Ex. . . . is the number of the original sample.

Lot B. 50 to 100 grams to be dried for one hour on a tray in an oven at 105° C., 2 large and 10 small sample tubes to be filled full, and 5 small tubes to be one-fourth filled with the dried coal. These tubes are to be labelled Ex. . . . (dry).

Lot C. 200–300 grams of the coal to be placed in a tray and weighed and stirred at intervals for six months or more, the trays being kept in a dust-free box exposed to air. This was called Ex. . . . (special).

Lot D. A bottle was filled with the remainder, dated with the day of grinding, and stored away labelled Ex. . . . (reserve).

The following analyses to be made on the different portions:—

Lot A. Moisture and ash to be determined at once and also an ultimate analysis to be made; moisture to be redetermined at three month intervals and also ultimate analyses made later.

Lot B. Complete analysis to be made at once and also six months later.

Lot C. Sample to be removed from tray from time to time for ultimate analysis, the tray to be weighed each time before and after the sample was removed in order that subsequent changes in weight could be calculated to percentages of original coal.

Table XIII shows the weights of coal in the trays from time to time; these are calculated to the basis of 100 parts of the original coal. Corrections have been made for the weights removed when samples were taken.

Tables XIV to XIX give the results of all analyses. Lines 4 and 5 give the percentage of moisture in the coal. All other analyses are reported upon dry coal in order that they may be comparable; to increase readiness of comparison, analyses are also reported corrected to dry and ash free coal. In all cases where it is of any moment, it is clearly indicated whether the analysis from which a figure is obtained was made upon a raw or a dried sample.

All actual determinations, corrected for moisture if necessary, are indicated by the addition, enclosed in brackets, of the date on which the determination was made; no deduced values have dates attached. No moisture determinations were made on the Ex. .... (special) samples taken from the trays on April 3, 1909, the moisture in these samples is calculated from that found two months later, by assuming that the change in weight in the trays in the meanwhile was entirely due to gain in moisture. Ash was determined in the Ex. .... (raw) samples, in the dry coal left from the moisture determinations; this was assumed to also give the ash in the corresponding Ex. .. (dry) sample. In the same way it is obvious that no serious error has been made by assuming that Ex....(raw) and Ex....(special) have the same sulphur and nitrogen content in the dry coal as was found in the corresponding Ex.... (dry) sample.

Ultimate analyses on Ex.... (raw) and Ex.... (dry), instead of being made promptly as intended, were unavoidably delayed for about 8 months. It is almost certain that by the time these analyses were made the raw samples had lost moisture—unless they were already in an air dry condition—and the dry samples had taken up moisture. The ultimate analyses on Ex.... (special) are less open to criticism. Discrepancies between the ultimate analyses of these three sets of samples indicate fairly clearly the probable magnitude of the error in moisture content.

TABLE XIII  
WEATHERING TESTS OF COAL

Ground coals exposed in trays on July 17, 1908.

Sample number.....	Ex. 27	Ex. 28	Ex. 16	Ex. 15	Ex. 18	Ex. 17	Ex. 19	Ex. 20	Ex. 21	Ex. 23	Ex. 22	Ex. 25	Ex. 26	Ex. 24
Weight of original coal in tray..... grams	351.3	353.5	44.7	233.5	79.5	94.4	93.2	108.3	87.3	75.3	77.5	28.3	210.4	48.1
Weight of coal at different dates corrected to 100 parts of original coal—														
August 4, 1908	99.2	97.8	100.2	100.0	100.1	99.8	100.2	99.8	100.2	100.3	99.9	101.1	100.6	89.4
August 15	99.4	98.1	100.1	100.4	100.3	99.9	99.9	99.7	99.9	100.0	99.5	100.7	100.7	89.4
September 9	98.6	97.1	100.1	99.8	100.3	99.7	100.2	99.7	100.0	100.5	100.0	101.4	100.3	88.3
October 2	98.8	97.0	100.0	99.8	100.0	99.4	99.9	99.6	99.7	100.0	99.5	100.4	100.5	87.5
February 23, 1909	98.1	93.4	99.6	95.9	100.0	97.8	99.7	99.3	98.7	99.9	99.4	100.0	99.7	84.0
April 3	98.2	93.6	99.9	96.1	100.0	98.2	100.0	99.5	98.8	100.1	99.2	101.4	99.9	84.2
June 12	99.1	95.4	100.0	98.5	100.8	99.3	100.4	100.1	99.4	100.8	99.7	101.8	100.9	86.1
August 9	99.0	96.2	100.3	99.2	101.0	99.5	100.6	100.5	100.1	101.5	99.9	101.8	101.4	89.3
November 19	98.7	94.4	100.3	96.9	100.8	98.5	100.4	100.1	98.9	101.1	99.7	101.8	100.4	84.9
December 26, 1911	100.3	94.7	100.8	97.3	101.0	98.5	100.4	100.6	99.2	102.3	100.1	102.3	101.5	85.5



## SPONTANEOUS COMBUSTION OF COAL

(Being a paper read before the Canadian Mining Institute, March, 1910, by Edgar Stansfield, M.Sc., McGill University, Montreal.)

## Introductory Note.

The writer of the following paper had hoped that when the regular work of the coal tests was completed he would be able to carry out an investigation on the spontaneous combustion of coal. As a preparation for this work he made a study of the literature of the subject, and wrote the following summary for presentation to the Annual Meeting of the Canadian Mining Institute, held at Toronto, March 1910. He was, however, unable to take part in this investigation himself, but Dr. J. B. Porter, with other assistants, has carried on an investigation during the past two years, and it is hoped to publish their results, together with a further historical introduction, within a few months, as Vol. VII of this report.

The paper is reprinted, by permission, from Volume XIII of the proceedings of the Canadian Mining Institute. Some small changes have been made; but no attempt has been made to bring it up to date. For further and later information Volume VII should be consulted.

. . . . .

The deterioration of stored coal is a very serious matter to all large dealers and consumers, and fuller and more definite information on the subject is urgently needed. A study of the extensive literature bearing upon spontaneous combustion has shown that although much has been accomplished, a great deal more remains to be done. This literature<sup>1</sup> is not easily accessible and although there have been excellent summaries published, these chiefly refer to the question of the shipment of coal cargoes, so that there does seem a need for a statement as to the known facts and present theories with especial reference to land storage. It is this need that the present paper is an attempt to fulfil.

Spontaneous combustion of coal may be considered under three classes: fires in the mines, fires in ships, and fires in land storage. All these may at times be of very grave importance; they have all three caused the loss of incalculable sums of money and the first two have resulted in the loss of very many lives.

A few examples will illustrate the importance of the subject:—

At the Hamstead colliery in South Staffordshire, England, is worked what is known as the "Thick Coal Seam," there about 20 feet thick. This seam is not gassy, but is extremely liable to fire spontaneously. There were no less than 200 fires in the 20,000 feet of return airways in 1895, and 250 in 1896. In November 1898 a fire broke out so suddenly and acquired

<sup>1</sup> The writer wishes to acknowledge his great indebtedness for aid in the writing of the paper, and for his diagrams to the Report of the New South Wales Royal Commission (1897), and to a paper by Prof. R. Threlfall "The Spontaneous Heating of Coal Particularly During Shipment" (J. Soc. Chem. Indust. July 31, 1909, pp. 759-773). The following papers have also been freely made use of: "The Spontaneous Ignition of Coal and its Prevention," by Prof. Vivian B. Lewes (J. Soc. of Arts, Vol. 40, 1892, pp. 352-365), and "The Spontaneous Combustion of Coal on Board Ship," by Commander W. F. Caborne, C.B., R.N.R., (J. Roy. United Services Inst., XLVI, p. 285, and reprinted in The Mining Journal LXXII, 1902, p. 124 *et seq.*).

such magnitude that the mine had to be closed, and this in spite of elaborate precautions and almost constant inspection.

In the nine years between 1873 and 1883, fifty-seven boats leaving British ports with coal cargoes are known to have been lost owing to spontaneous combustion. Three hundred and twenty-eight others disappeared during the same time, and we can only guess at their fate. These figures only refer to vessels actually lost. In 1874 alone, seventy cargoes either fired or heated.

During the last two or three years the writer has seen or heard of several spontaneous fires of both Cape Breton and Pennsylvanian coal stored in Montreal. The following is an extract from a letter received by Dr. Porter from the President of an Ontario firm using Pennsylvanian slack coal: "With reference to the trouble with our coal pile here, I am sorry to say that the conditions got very much worse after I wrote you on September 24, and I found that the greater part of the dump was beginning to heat. . . . The only lot of coal that we have that does not appear to be more or less hot is one comparatively small pile that stands by itself. . . . I must say our experience this year has discouraged me from trying to handle a large dump of slack coal, which is very unfortunate, as it is much the cheapest and most satisfactory way for us to handle our coal, as we have our own boats, and plenty of space to pile it; whereas, in the winter, there is always more or less trouble, in bad weather, in getting a regular supply of cars."

The above cases are all of more or less open combustion; but, as will be shown later, all coal, even though not perceptibly warm, is in a state of combustion for at any rate many months after it is mined, and this combustion, of course, means deterioration.

Trouble with coal cargoes at sea has materially decreased of recent years, largely owing to a decrease of length of time of voyages and an increase of knowledge; but on land, especially in Canada, trouble from the heating of coal is probably on the increase.

In all the great manufacturing countries, large concerns are more and more compelled to have large reserves of coal on hand. The admiralities carry coal stocks as a preparation for war; manufacturing firms to reduce the dislocation caused by strikes at the mines, or in the carrying trades, or merely to tide over fluctuations in the price or supply of the coal they require.

Here in Canada the nature of our winter almost compels the storage of very large quantities of coal, especially at such places as Montreal, where coal can be obtained comparatively cheaply in summer by water, but where the railway freight necessary in winter renders the price almost prohibitive.

One railway company stacks from 200,000 to 250,000 tons of coal in Montreal alone each year, and the constant expense and trouble to which it is put to avoid fires, to say nothing of the loss due to the deterioration of

the coal, are enormous. Every railway company, every coal dealer, and every large consumer has also to store coal.

Enough has been said to show the great importance of the subject under discussion and also to show that any information that would in future result in reducing the losses on stored coal, even if only by one cent a ton, would be a valuable asset to the community.

The coal from the Hamstead colliery referred to above, being extremely apt to fire spontaneously, forms a good starting point in studying the question. Messrs. Haldane and Meachem have brought forward much interesting information in this connexion.<sup>1</sup>

They state that the mean temperature of the air at the foot of the shaft in the intake airway is 60° F. and in the return airway is 77° F. The natural temperature of the undisturbed strata at the level of the pit bottom is only 68° F., so that the whole of this rise in temperature of the air cannot be due to the natural heat in the strata; on the contrary, the strata is being gradually heated from the mine. "The coal behind an exposed surface gradually rises in temperature, month by month, and year by year. Thus at two places in the side of a main road, where the temperature at the end of 10 ft. boreholes was 66° F. in 1894 it had risen to 83° F. and 90° F. in 1898."

They calculate that every cubic foot of air passed through, removes one British Thermal Unit of heat from the mine; also that of this quantity of heat at the outside 7 per cent could be accounted for by the presence of horses, men, and burning candles, 10 per cent by the settling of the superincumbent strata, and 2 per cent by the friction of the air. This leaves over 80 per cent unaccounted for. "The only other possible source of heat in the mine is the chemical action of the air on the exposed coal and other material."

Temperatures were taken at different points in the airways and analyses made of samples of air taken at the same points. The analyses show that as the air passes through the pit it steadily loses oxygen and gains carbon dioxide, the average loss being 3·13 times the gain (in most collieries this ratio is said to be about 1·6). The following table, Table XX, clearly shows the intimate relation existing between the rise in temperature and the decrease in oxygen:—

TABLE XX

Temperature	Decrease in oxygen.	Temperature.	Decrease in oxygen.
55° F. ....	0·00%	78° F. ....	0·36%
71     ....	0·16	80     ....	0·77
73     ....	0·25	83     ....	0·88
74     ....	0·37	83     ....	1·70

The temperature of the air circulated through the mine does not rise steadily as it proceeds, because as it returns from the working face it

<sup>1</sup> "Observations on the Relation of Underground Temperature and Spontaneous Fires in the Coal to Oxidation and to the Causes which Favour it," by J. S. Haldane, M.D., F.R.S., and F.G. Meachem, M.I.M.E., Trans. Inst. M.E., 1898, Vol. XVI, pp. 457-492.

is cooled from time to time by leaks from the intake airway, so that the foot of the upcast shaft is by no means the hottest place in the mine.

Haldane and Meachem have also made laboratory experiments on this coal in which they filled a quart sized flask with roughly powdered coal and left the flask sealed up in connexion with a mercury pressure gauge. They found that the pressure of the air in the flask steadily decreased for some time (unless the coal in the flask was very fresh, in which case the pressure first rises owing to the evolution of hydrocarbons), and an analysis of the residual gas then showed it to be almost pure nitrogen.

The following figures, Table XXI, show the course of such an experiment. The coal, which had been lying in lumps in the laboratory for three months after being mined, was crushed in a mortar and left lying in a thin layer (to allow any gas to escape) for two hours before putting into the flask. The temperature of the flask was about 54° F.; the pressure readings were corrected for changes of temperature and barometric pressure.

TABLE XXI.

Time since closing flask.	Negative pressure of mercury.	Time since closing flask.	Negative pressure of mercury.
1 hour.....	0.15 inches	4 days.....	5.05 inches
5 hours.....	0.65 "	5 ".....	5.45 "
12 ".....	1.25 "	6 ".....	5.75 "
24 ".....	2.00 "	7 ".....	6.00 "
36 ".....	2.80 "	9 ".....	6.10 "
48 ".....	3.40 "	11 ".....	6.10 "
56 ".....	3.85 "	24 ".....	6.00 "
72 ".....	4.30 "	6 months.....	5.85 "

The analysis of the gas left in the flask at the end is shown in Table XXII.

TABLE XXII.

Constituents	Percentage
Oxygen.....	0.07
Carbon dioxide.....	1.28
Methane.....	0.65
Carbon monoxide.....	0.04
Nitrogen.....	97.96

This experiment shows, what had already been proved by Dr. Richters in 1868, that coal absorbs oxygen, presumably with the evolution of heat, as it was shown above that the decrease of oxygen in the air in the mine was accompanied by a rise in temperature.

Another series of experiments performed by Haldane and Meachem consisted in passing air at a measured rate through a layer of coal in a flask, the flask being immersed in a water bath the temperature of which could be kept constant at any desired heat. Samples of the air that had passed through the coal were removed from time to time for analysis. Table XXIII shows the results of two such experiments:—

TABLE XIV  
WEATHERING TESTS OF COAL

SAMPLES OF COAL FROM THE DOMINION COAL CO., DOMINION No. 12, LINGAN, C.B.											
1. Source of coal	Regular samples, coal taken from dump, mined a few hours before run of mine coal		Extra sample for coking tests.	Sample Ex. 27 for weathering tests taken one-third distance from roof, in main slope, 125 feet away from Ex. 28. Exposed for three or four months				Sample Ex. 28 waterop coal for weathering tests, taken from main slope at point of natural outcrop, from untimbered entrance, and from same bench in seam as sample Ex. 27.			
2. Description of samples	(27-vi-08)		(20-vi-09)	(27-vi-08)				(27-vi-08)			
	Regular sample	Mine moisture sample		Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Exposed on tray (17-vii-08)		Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Exposed on tray (17-vii-08)	
				Raw coal put in tubes. (3-iv-08)	Raw coal put in tubes. (12-vi-09)	Raw coal put in tubes. (3-iv-09)	Raw coal put in tubes. (12-vi-09)	Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Raw coal put in tubes. (3-iv-09)	Raw coal put in tubes. (12-vi-09)
3. Sample number	39	139	2039	Ex. 27 (raw)	Ex. 27 (dry)	Ex. 27 (special)	Ex. 27 (special)	Ex. 28 (raw)	Ex. 28 (dry)	Ex. 28 (special)	Ex. 28 (special)
Moisture in coal											
4. Total moisture	4.1 (21-xii-08)	4.9 (vii-08)		4.2 (2-xi-08)		1.4	2.3 (21-vi-09)	10.1 (2-xi-08)		4.0	6.1 (21-vi-09)
Moisture in dry coal		3.6 (30-vii-08)									
Proximate analysis of coal											
5. Fixed carbon in dry coal— <i>from analysis of raw coal (R)</i>	57.2						58.8				57.1
6. " " " <i>from analysis of dry coal (D)</i>	60.1		58.8		58.0			56.8			
7. " " " in dry and ash free coal— <i>from R</i>	60.9				59.1		60.0		59.8		60.1
8. " " " <i>from D</i>			61.3								
10. Volatile matter in dry coal— <i>from analysis of raw coal (R)</i>	38.0 (1-ii-09)						39.3 (12-vi-09)				38.0 (12-vi-09)
11. " " " <i>from analysis of dry coal (D)</i>	37.2 (12-viii-08)		37.1 (2-iii-09)		40.0 (30-x-08)			37.8 (30-x-08)			
12. " " " in dry and ash free coal— <i>from R</i>	39.9				40.0 (11-vi-09)		40.0	38.6 (11-vi-09)			39.9
13. " " " <i>from D</i>	39.1		38.7		40.9			40.2			
14. Ash in dry coal—coal burnt in muffle	4.8 (29-vii-08)	6.3 (31-vii-08)	4.1 (1-iv-09)	2.0 (2-xi-08)	2.0		1.9 (22-vi-09)	5.0 (2-xi-08)	5.0		4.9 (22-vi-09)
15. Fuel ratio FC/VM— <i>from R</i>	1.51						1.50				1.50
16. " " " <i>from D</i>	1.56		1.58		1.45				1.49		
Ultimate analysis of coal											
17. Carbon in dry coal— <i>from analysis of raw coal (R)</i>	77.7 (6-iii-09)		80.4 (2-iii-09)	82.5 (2-iii-09)	81.0 (iii-09)	80.0 (3-iv-09)	74.2 (iii-09)	71.9 (iii-09)		69.2 (3-iv-09)	
18. " " " <i>from analysis of dry coal (D)</i>				84.3		84.8	78.1	75.5		72.7	
19. " " " in dry and ash free coal— <i>from R</i>	82.1				82.7						
20. " " " <i>from D</i>			84.3								
21. Hydrogen in dry coal— <i>from analysis of raw coal (R)</i>			5.48 (2-ii-09)	5.33 (2-iii-09)	5.44 (iii-09)	5.46 (3-iv-09)	4.43 (iii-09)	4.49 (iii-09)		4.45 (3-iv-09)	
22. " " " <i>from analysis of dry coal (D)</i>	5.18 (6-iii-09)			5.44		5.58	4.35	4.72		4.67	
23. " " " in dry and ash free coal— <i>from R</i>			5.48	5.74		5.65					
24. " " " <i>from D</i>											
25. Sulphur in dry coal	1.8 (11-xiii-08)		1.6 (13-vii-09)	1.1	1.1 (23-vi-09)	1.1		0.6 (22-vi-09)	0.6		0.6
26. " " " in dry and ash free coal	1.9		1.7	1.1	1.1			0.6		0.6	
27. Nitrogen in dry coal	1.6 (10-v-08)		1.6 (2-vi-09)	1.7	1.7 (7-vi-09)	1.7	1.5	1.5 (7-vi-09)	1.5		1.5
28. " " " in dry and ash free coal	1.7		1.7	1.7	1.7		1.6	1.6		1.6	
29. Oxygen in dry coal— <i>from analysis of raw coal (R)</i>				7.3		9.5	14.6			10.4	
30. " " " <i>from analysis of dry coal (D)</i>	8.3		6.3		8.7			16.7			
31. " " " in dry and ash free coal— <i>from R</i>				7.5		9.8	15.3	17.6		20.4	
32. " " " <i>from D</i>	8.8		6.6		8.8						
33. Ash in dry coal—coal burned in oxygen	5.4 (6-ii-09)		4.6 (2-iii-09)	2.1	2.0 (iii-09)	2.2		5.0 (iii-09)	4.8 (iii-09)		4.8 (3-iv-09)
34. Carbon-hydrogen ratio, C/H— <i>from R</i>				15.5		14.6		18.0		15.5	
35. " " " <i>from D</i>	15.0		14.7		14.6			16.0			
Calorific value of coal											
36. On dry and ash free coal— <i>from determination</i>											
37. " " " <i>from ultimate analysis</i>			8340	8390	8270	8140	7170	6980		6620	
38. Colour of ground coal						Black with brown tinge				Black	
39. Coking properties					Fairly good but friable coke		Fairly good coke		Non-caking		Non-caking



SAMPLES OF COAL FROM THE WEST CANADIAN COLLIERIES CO., BELLEVUE COLLIERY, ALTA., SEAMS 1 and 2



WEATHERING TESTS OF COAL

1. Source of coal		SAMPLES OF COAL FROM THE WEST CANADIAN COLLIERIES CO., HILL COLLIERY, ALTA., No. 1 SEAM										
2. Description of samples		Regular samples, run of mine coal (6-v-08)		Extra sample for coking tests. (30-vii-09)	Sample Ex. 18 for weathering tests. Coal taken from side of seam after removing 8' of coal from surface at 24 feet from mouth of prospecting slope two years old (6-v-08)		Sample Ex. 17 for weathering tests. Old coal from surface of side of seam at 3 feet from mouth of prospecting slope two years old. This sample does not represent outcrop weathering. (6-v-08)					
		Regular sample	Mine moisture sample		Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Exposed on tray (17-vii-08) Raw coal put in tubes. (3-iv-09)      Raw coal put in tubes. (12-vi-09)		Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Exposed on tray (17-vii-08) Raw coal put in tubes. (3-iv-09)      Raw coal put in tubes. (12-vi-09)	
3. Sample number		28	128	2028	Ex. 18 (raw)	Ex. 18 (dry)	Ex. 18 (special)	Ex. 18 (special)	Ex. 17 raw	Ex. 17 dry	Ex. 17 (special)	Ex. 17 (special)
Moisture in coal		0.9 (2-xi-08)	1.7 (v-08)	1.5 (12-viii-09)	1.2 (2-xi-08)		0.2	1.0 (19-vi-09)	4.6 (2-xi-08)		2.2	3.2 (19-vi-09)
4. Total moisture		%	%	%	%	%	%	%	%	%	%	%
5. Moisture in air dry coal		58.8	68.5	68.5	62.4		63.5		61.7		64.4	
6. Fixed carbon in dry coal—from analysis of raw coal (R)		%	%	%	%	%	%	%	%	%	%	%
7. " " "—"from analysis of dry coal (D)		%	%	%	%	%	%	%	%	%	%	%
8. " " "in dry and ash free coal—from R		%	%	%	%	%	%	%	%	%	%	%
9. " " "—"from D		%	%	%	%	%	%	%	%	%	%	%
10. Volatile matter in dry coal—from analysis of raw coal (R)		%	24.8 (28-i-09)		30.4 (30-x-08)		29.2 (12-vi-09)		28.1 (30-x-08)		25.6 (12-vi-09)	
11. " " "—"from analysis of dry coal (D)		%	25.1 (25-vi-08)	25.3 (13-viii-09)	29.9 (11-vi-09)		31.5		26.2 (11-vi-09)		28.8	
12. " " "in dry and ash free coal—from R		%	29.7		32.5				30.5			
13. " " "—"from D		%	30.0	30.0								
14. Ash in dry coal—coal burnt in muffle.		%	16.4 (24-vi-08)	16.0 (13-vi-08)	15.8 (13-viii-09)	7.5 (29-x-08)	7.5	7.3 (21-vi-09)	11.2 (29-x-08)	11.2		11.0 (21-x-09)
15. Fuel ratio FC/VM—from R			2.37		2.32			2.48				
16. "—"from D			2.33									
Ultimate analysis of coal												
17. Carbon in dry coal—from analysis of raw coal (R)		%			80.5 (ii-09)		79.7 (3-iv-09)		72.5 (ii-09)		71.5 (3-iv-09)	
18. " " "—"from analysis of dry coal (D)		%	71.2 (4-i-09)		80.1 (ii-09)		80.1 (ii-09)		71.6 (25-ii-09)		80.6	
19. " " "in dry and ash free coal—from R		%			86.8		86.1		81.8			
20. " " "—"from D		%	85.2		86.6				80.6			
21. Hydrogen in dry coal—from analysis of raw coal (R)		%			4.61 (ii-09)		4.86 (3-iv-09)		3.53 (ii-09)		3.82 (3-iv-09)	
22. " " "—"from analysis of dry coal (D)		%	4.28 (6-i-09)		4.97		5.25		3.99		4.30	
23. " " "in dry and ash free coal—from R		%										
24. " " "—"from D		%	5.09				5.24		4.38			
25. Sulphur in dry coal		%	0.5 (20-vi-08)		0.6 (14-viii-09)	0.8	0.8 (21-vi-09)	0.8	0.5	0.5 (21-xi-09)	0.5	
26. " " "in dry and ash free coal		%	0.6		0.9	0.9	0.9	0.9	0.6	0.6	0.6	
27. Nitrogen in dry coal		%	0.9 (6-v-08)		1.1	1.1	1.1 (4-vi-09)	1.1	0.8	0.8 (4-vi-09)	0.8	
28. " " "in dry and ash free coal		%	1.1		1.2	1.2		1.2	0.9	0.9	0.9	
29. Oxygen in dry coal—from analysis of raw coal (R)		%			5.7		6.0		11.4		12.2	
30. " " "—"from analysis of dry coal (D)		%	6.7				5.7		12.1			
31. " " "in dry and ash free coal—from R		%			6.1		6.5		12.7		13.6	
32. " " "—"from D		%	8.0						13.5			
33. Ash in dry coal—coal burned in oxygen		%	16.4 (4-i-09)			7.3 (ii-09)	7.5 (ii-09)	7.5 (3-iv-09)	11.3 (i-09)	11.1 (25-i-09)	11.2 (3-iv-09)	
34. Carbon-hydrogen ratio, C/H—from R									20.5		18.7	
35. "—"from D			18.8				16.5			18.4		
Caloric value of coal												
36. On dry and ash free coal—from determination		calories	8290 (10-v-09)		8330 (27-x-09)		8370	8310	7450	7450	7420	
37. "—"from ultimate analysis		calories	8300		8400							
38. Colour of ground coal								Brownish black			Black	
39. Caking properties						Medium hard coke		Hard coke		Non-caking		Non-caking



TABLE XVII

SAMPLES OF COAL FROM THE INTERNATIONAL COAL & COKE CO., COLEMAN, ALTA., No. 4 SEAM, DENISON COLLIERY



TABLE XVIII  
WEATHERING TESTS OF COAL

1. Source of coal		SAMPLES OF COAL FROM THE CROWNSNEST PASS COAL CO. No. 3 MINE, MICHEL COLLIERY, B.C.									
2. Description of samples		Regular samples, coal over 2" screen and picking belt. (30-iv-08)	Extra sample for coking tests. (27-vii-09)	Sample Ex. 23 for weathering tests. Taken in old upple tunnel, 30 feet from mouth, after removing 10" to 12" of the surface coal. Surface had been exposed 8½ years. (7-v-08)				Sample Ex. 22 for weathering tests. Coal exposed 5½ years. Taken in old upple tunnel 30 feet from mouth by scraping exposed surface with ring-ro. (7-v-08)			
		Regular sample	Mine moisture sample	Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Exposed on tray (17-vii-08)		Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Raw coal put in tubes. (12-iv-09)	Raw coal put in tubes. (12-vi-09)
3. Sample number.		31	131	2031	Ex. 23 (raw)	Ex. 23 (dry)	Ex. 23 (special)	Ex. 23 (special)	Ex. 22 (raw)	Ex. 22 (dry)	Ex. 22 (special)
4. Total moisture.		0.7 (2-xi-08)	1.4 (v-08)	1.0 (13-viii-08)	1.0 (29-x-08)		0.1	0.7 (21-vi-09)	1.4 (20-x-08)	0.0	0.3 (21-vi-09)
5. Moisture in air dry coal.			0.4 (11-vi-08)								
Proximate analysis of coal											
6. Fixed carbon in dry coal—from analysis of raw coal (R).		62.4						71.4			55.2
7. " " " "—"from analysis of dry coal (D).		62.8		66.0		71.6				55.0	
8. " " " "—"from R.		71.3						73.8			71.0
9. " " " "—"from D.		71.8		75.6		74.0				79.7	
10. Volatile matter in dry coal—from analysis of raw coal (R).		25.1 (28-i-09)						25.3 (13-vi-09)			22.6 (14-xviii-09)
11. " " " "—"from analysis of dry coal (D).		24.7 (10-vi-08)		21.5 (13-viii-09)		25.0 (30-x-08)				25.1 (30-x-08)	
12. " " " "—"from R.		28.7				23.2 (11-vi-09)		26.2 (11-vi-09)			26.0
13. " " " "—"from D.		28.2		24.4		26.0				29.3	
14. Ash in dry coal—coal burnt in muffle.		12.5 (17-vi-08)	10.0 (13-vi-08)	11.9 (14-viii-09)	3.3 (29-x-08)	3.3		3.3 (22-vi-09)	22.2 (20-x-08)	22.2	22.2 (22-viii-09)
15. Fuel ratio FC/VM—from R.		2.49						2.82			2.44
16. " " " "—"from D.		2.54		3.10		2.85				2.41	
Ultimate analysis of coal											
17. Carbon in dry coal—from analysis of raw coal (R).					86.1 (iii-09)		81.8 (3-iv-09)		67.7 (iii-09)		67.1 (iv-09)
18. " " " "—"from analysis of dry coal (D).						85.3 (iii-09)				66.8 (iii-09)	
19. " " " "—"from R.		75.5 (9-i-09)		89.1			87.7		87.5		86.0
20. " " " "—"from D.		80.4				88.3				86.2	
21. Hydrogen in dry coal—from analysis of raw coal (R).					4.89 (iii-09)		4.90 (3-iv-09)		4.24 (iii-09)		4.29 (iv-09)
22. " " " "—"from analysis of dry coal (D).		4.3 (9-i-09)				5.02 (iii-09)				4.29 (iii-09)	
23. " " " "—"from R.					5.06		5.16		5.48		5.38
24. " " " "—"from D.		4.9				5.19				5.66	
25. Sulphur in dry coal.		0.5 (15-vi-08)		0.5 (16-viii-09)	0.4		0.4 (22-vi-09)	0.4	0.5	0.3 (22-vi-09)	0.5
26. " " " "—"dry and ash free coal.		0.6			0.4		0.4		0.6		0.6
27. Nitrogen in dry coal.		1.2 (8-v-08)			1.5		1.5 (5-vi-09)	1.5	1.2	1.3 (5-vi-09)	1.2
28. " " " "—"dry and ash free coal.		1.4			1.5		1.5		1.5		1.5
29. Oxygen in dry coal—from analysis of raw coal (R).					3.7		5.0		3.8		5.0
30. " " " "—"from analysis of dry coal (D).						4.5				4.0	
31. " " " "—"from R.		5.9			3.9		5.2		4.9		6.5
32. " " " "—"from D.		6.7				4.6				6.0	
33. Ash in dry coal—coal burned in oxygen.		12.6 (9-i-09)			3.4 (iii-09)	3.3 (iii-09)	3.3 (3-iv-09)		22.6 (iii-09)	22.5 (iii-09)	22.6 (iv-09)
34. Carbon-hydrogen ratio, C/H—from R.					17.6		17.40		16.0		16.0
35. " " " "—"from D.		17.5				17.0				15.2	
Calorific value of coal											
36. On dry and ash free coal—from determination.		8420 (27-iv-09)		8520 (16-xi-09)	8780	8730	8640		8760	8660	8740
37. " " " "—"from ultimate analysis.		8370									
38. Colour of ground coal							Black				Rather brown
39. Coking properties.		Cokes				Cokes		Cokes		Hard coke	Cokes fairly well



TABLE XIX

WEATHERING TESTS OF COAL

1. Source of coal.		SAMPLES OF COAL FROM THE NICOLA VALLEY COAL & COKE CO., No. 2 MINE, MIDDLESBORO COLLIERY, B.C.													
2. Description of samples.		Regular samples, coal taken from bank, freshly mined run of mine coal.		Sample Ex. 25, for weathering tests; fresh coal taken 1400 feet from portal.				Sample Ex. 26, for weathering tests, weathered coal taken 80 feet from portal, where it had been exposed for 10½ months.				Sample Ex. 24, for weathering tests, outcrop coal taken from under 3 feet of surface drift.			
		(18-iv-08)		(2-vi-08)				(2-vi-08)				(2-vi-08)			
		Regular sample	Mine moisture sample	Raw coal put in tubes. (vii-08)	Dry coal put in tubes. (vii-08)	Exposed on tray (17-vii-08) Raw coal put in tubes. (3-ix-09)      Raw coal put in tubes. (12-ix-09)		Raw coal put in tubes. (vii-08)	Dried coal put in tubes. (vii-08)	Exposed on tray (17-vii-08) Raw coal put in tubes. (3-ix-09)      Raw coal put in tubes. (12-ix-09)		Raw coal put in tubes. (vii-08)	Dried coal put in tubes. (vii-08)	Exposed on tray (17-vii-08) Raw coal put in tubes. (3-ix-09)      Raw coal put in tubes. (12-ix-09)	
3. Sample number.	22 SP.	122 SP.	Ex. 25 (raw)	Ex. 25 (dry)	Ex. 25 (special)	Ex. 25 (special)	Ex. 26 (raw)	Ex. 26 (dry)	Ex. 26 (special)	Ex. 26 (special)	Ex. 24 (raw)	Ex. 24 (dry)	Ex. 24 (special)	Ex. 24 (special)	
Moisture in coal	2.7 (18-iv-08)	2.9 (vii-08)	2.6 (29-x-08)		1.3	1.7 (21-vi-09)	4.1 (2-xi-08)		1.2	2.1 (21-vi-09)	25.5 (29-x-08)		7.4	9.5 (21-vi-09)	
4. Total moisture.	2.8 (30-vii-08)														
5. Moisture in air dry coal.															
Proximate analysis of coal															
6. Fixed carbon in dry coal—from analysis of raw coal (R)	47.3					54.8				53.7				45.0	
7. " " "—"from analysis of dry coal (D)	48.1			54.5				52.5				47.8			
8. " " " in dry and ash free coal—from R.	54.3					57.1				56.0				50.2	
9. " " "—"from D.	55.2			56.7				54.6				52.3			
Volatile matter in dry coal—from analysis of raw coal (R)															
10. " " "—"from analysis of dry coal (D)	39.8 (28-i-09)			40.8 (30-x-08) 42.4 (11-vi-09)		41.1 (12-vi-09)		44.0 (30-x-08) 43.2 (11-vi-09)		42.4 (12-vi-09)		43.2 (30-x-08) 43.9 (11-vi-09)		45.4 (12-vi-09)	
11. " " " in dry and ash free coal—from R.	45.7					42.9				44.0				49.8	
12. " " "—"from D.	44.8			43.8				43.4				47.7			
13. Ash in dry coal—coal burnt in muffle.	12.9 (19-vi-08)	11.4 (30-vii-08)	3.9 (29-x-08)	3.9		4.1 (22-vi-09)	3.9 (29-x-08)	3.9		3.9 (22-vi-09)	8.6 (29-x-09)	8.6		8.7 (22-vi-09)	
14. Fuel ratio FC/VM—from R.	1.19					1.33				1.27				1.01	
15. "—"from D.	1.23			1.31				1.20				1.10			
Ultimate analysis of coal															
16. Carbon in dry coal—from analysis of raw coal (R)			79.0 (iii-09)		78.1 (iv-09)		78.8 (iii-09)		77.3 (iv-09)		64.5 (iii-09)		61.9 (iv-09)		
17. " " "—"from analysis of dry coal (D)	69.4 (9-ii-09)			78.2 (iii-09)			82.2	76.6 (iii-09)	80.5		60.7 (iii-09)		67.5		
18. " " " in dry and ash free coal—from R.			82.4		81.6						70.5				
19. " " "—"from D.	79.9			81.7				79.7			66.0				
Hydrogen in dry coal—from analysis of raw coal (R)															
20. " " "—"from analysis of dry coal (D)	5.11 (9-ii-09)		5.70 (iii-09)		5.61		5.55 (iii-09)		5.74 (iv-09)		3.02 (iii-09)		3.82 (iv-09)		
21. " " " in dry and ash free coal—from R.			5.94		5.86 (iv-09)		5.79	5.85 (iii-09)	5.98		3.30		4.07 (iii-09)	4.13	
22. " " "—"from D.	5.88			6.13				6.09			4.42				
Sulphur in dry coal															
23. " " " in dry and ash free coal.	0.7 (15-vi-08)		0.5	0.5 (22-vi-09)	0.5		0.5	0.5 (22-vi-09)	0.5		0.4	0.4 (22-vi-09)	0.4		
24. " " "—"from D.	0.8		0.5	0.5	0.5		0.5	0.5	0.5		0.4	0.4	0.4		
Nitrogen in dry coal															
25. " " " in dry and ash free coal.	2.0 (5-v-08)		2.3	2.3 (7-vi-09)	2.3		2.2	2.2 (7-vi-09)	2.2		2.0	2.0 (5-vi-09)	2.0		
26. " " "—"from D.	2.3		2.4	2.4	2.4		2.2	2.3	2.3		2.2	2.2	2.2		
Oxygen in dry coal—from analysis of raw coal (R)															
27. " " "—"from analysis of dry coal (D)	9.7		8.4		8.8		9.2		10.3		21.5		23.6		
28. " " " in dry and ash free coal—from R.			8.8		9.6		9.2		10.7		23.6		25.8		
29. " " "—"from D.	11.1			9.3				11.4			27.0				
30. Ash in dry coal—coal burned in oxygen.	13.1 (9-ii-09)		4.1 (iii-09)	4.3 (iii-09)	4.3 (iv-09)		4.1 (iii-09)	3.9 (iii-09)	4.0 (iv-09)		8.6 (iii-09)	7.9 (iii-09)	8.3 (iv-09)		
31. Carbon-hydrogen ratio, C/H—from R.			13.9		13.9		14.2		13.5		21.4		16.2		
32. "—"from D.	13.6			13.3				13.1			14.9				
Calorific value of coal															
33. On dry and ash free coal—from determination	7760 (21-iv-09)														
34. "—"from ultimate analysis	8030		8340	8320	8210		8250	8060	8110		5820	5700	5780		
35. Colour of ground coal.					Black with brown tinge				Black				Very brown		
36. Coking properties.				Medium coke		Medium coke		Medium coke		Poor coke		Non-caking		Non-caking	



TABLE XXIII.

*Experiment I, with 0.92 pounds of finely pounded coal, sent from the pit 4 days previously and freshly pounded up.*

Tem- pera- ture of bath.	Time since coal was pounded up.	Rate of ventilation per hour.	Deficiency of oxygen.	Carbon dioxide increased.	Methane and carbon monoxide.	Oxygen absorbed per ton of coal and per hour.
°F.	Hours.	Cub. Ft.	Per cent.	Per cent.	Per cent.	Cub. Ft.
59	2	0.091	1.10	0.07	0.290	2.45
59	5	0.131	0.72	0.02	—	2.30
59	8	0.080	1.00	0.05	—	1.95
60	20	0.114	0.46	0.04	—	1.26*
101	25	0.114	1.29	0.05	0.075	3.58
108	29	0.114	1.48	0.12	0.100	4.11
125	32	0.103	2.18	0.10	0.110	5.59

\* Ventilation left on for 12 hours since last determination.

*Experiment II, with 2.7 pounds of pounded coal (same sample as used in last experiment) sent from the pit 3 months previously and fragments pounded up a few hours before the experiment.*

Tem- pera- ture of bath	Rate of ventila- tion per hour.	Deficiency of oxygen.	Carbon dioxide increased.	Methane.	Carbon monoxide.	Oxygen absorbed per ton of coal and per hour.
°F.	Cub. Ft.	Per cent.	Per cent.	Per cent.	Per cent.	Cub. Ft.
59	0.078	0.40	0.09	0.00	0.00	0.26
160	0.084	5.31	0.67	0.07	0.14	3.70

A sample of coal, from another pit, which had stood in lumps in the laboratory for about two years, was still found to absorb oxygen when pounded up.

Haldane and Meachem deduce the following important results from these experiments.

(1) The rate of absorption of oxygen by coal is proportional to the partial pressure of the oxygen present.

(2) The rate of absorption of oxygen is approximately doubled for every 30° F. rise in temperature.

(3) The rate of absorption of oxygen at any temperature decreases as time goes on; at 59° F. it falls to half value after 20 hours.

(4) The absorption of oxygen takes place on the surface, thus lump coal that had been exposed to the air for two years would absorb more oxygen when fresh surface was exposed by crushing.

The experiments, by which the numerical values given are deduced, are open to criticism, but in any case these figures would vary with every different sample of coal. The general conclusions, however, are probably correct and bearing these in mind we can now go on to study the conditions existing in coal piles.

A pile of coal is in itself a very poor conductor of heat. This is shown by the fact that snow has been known to remain a whole year under a coal pile. The writer has heard of coal, stored during the winter in Cape Breton, brought up to Montreal during the spring or summer and rebanked, still having Cape Breton snow mixed with it when it was dug out of the pile in Montreal. Again, it is customary to test the temperature of a coal pile by means of iron rods pushed down through the coal; it has not infrequently happened that fire has been detected in a pile within 3 or 4 feet of a cool rod. We can, therefore, neglect the heat conductivity of the coal itself and assume that the only way in which heat generated in the pile can escape is by means of air currents. Again, on account of its low conductivity, after once a coal pile has been made the atmospheric temperature can have little effect below the surface except through air currents.

We will now consider a coal pile through which there is a slow circulation of air.

Then:—(1) Unless the surfaces exposed are already oxidized, oxygen will be absorbed from the air by the coal and heat will be evolved.

(2) Unless the heat of oxidation is carried away by the air current as fast as it is generated, the temperature of the coal will rise.

(3) As the temperature of the coal rises its rate of oxidation increases, that is, heat is generated more rapidly, so that the hotter the coal is, the more rapidly it tends to get hotter still, unless some secondary effect comes into play keeping it cool. The increase of rate of oxidation with increase of temperature will vary with different coals and although the velocity of oxidation may not be doubled for every 30° F. rise, as is said to be the case with Hamstead coal, the rate of increase is undoubtedly rapid. In the case of chemical reactions where the reacting substances are in intimate contact, as for example in solutions, the velocity of reaction approximately doubles for every 18° F. rise in temperature.

(4) As the temperature of the coal rises, the number of its constituents that can oxidize with noteworthy speed is increased.

(5) At any given temperature the rate of oxidation of the coal, that is, the rate of evolution of heat, will decrease as time goes on; this being due, of course, to the gradual completion of the oxidation of the readily oxidizable constituents of the coal.

(6) The higher the temperature and the more rapid the oxidation, the greater the air current will have to be to supply the necessary oxygen. At the same time, the higher the temperature at any spot in a coal pile is above the rest of the pile and the outside air the more convection currents will be set up. A warm spot in a pile may thus cause its own cure by setting up convection currents sufficient not only to supply the oxygen being absorbed, but also to carry away the heat faster than it is being generated, and in this way to cool the spot.

Generally, after a coal pile has been built, the temperature at any place inside the pile slowly rises, the oxidation of the fresh coal being com-

paratively rapid; after a while, owing to the gradual completion of the oxidation of the surface exposed and to the cooling effect of the convection currents, the rise of temperature comes to an end and the coal begins to get cooler, ultimately reaching atmospheric temperature. Occasionally, however, the first rise in temperature will take the coal above what may be described as the critical temperature; the oxidation is then so rapid that the retarding and cooling influences are insufficient, and the coal goes on getting hotter and hotter until it is in open combustion.

A coal pile is more likely to catch fire if:—

- (a) The coal is an easily oxidizable one.
- (b) The surface of coal exposed is large.
- (c) Air is supplied at a rate sufficiently fast to supply the required oxygen but no faster.
- (d) The heat generated cannot readily escape, and
- (e) The initial temperature is high.

We will now proceed to consider these conditions. (a) is confirmed by Prof. Fischer of Göttingen, who states that coals which rapidly absorb bromine are those which are most liable to rapid oxidation and spontaneous ignition. He recommends, as a practical test, shaking one gram of the finely ground coal with 20 c.c. of a half normal solution of bromine for five minutes. If the smell of bromine has then disappeared, the coal is liable to oxidize rapidly and is not a safe one to store. Prof. Lewes states that a coal that gains more than 2 per cent in weight, when heated to 250° F. for three hours, is dangerous.

(b) As was shown before, the oxidation of the coal is a surface action, and the more surface there is exposed the more rapid is the action. Piles of lump coal rarely, if ever, catch fire; the danger is with run of mine or slack coal in which the surface exposed is so much larger in comparison with the weight. On shipboard, fires usually begin in the pile of broken coal formed under the hatches during loading. It is well known that cotton waste soaked in oil is liable to catch fire. There is in this case a large surface of the oxidizable material exposed in comparison with its weight.

(c) and (d). These conditions are most likely to be met with in a large pile. Inside such a pile it is not easy for the heat to escape, and although in one spot the air circulation may be too rapid and in another too slow, the probability of the circulation being just right in some place is greatly increased. The increase of danger with the height and size of the pile has been repeatedly proved. The most striking proof has been supplied by H. Fayol.<sup>1</sup>

An account of H. Fayol's excellent work at Commentry, in France, will be found in Prof. Threlfall's paper referred to above, or better still in the 1897 Report of the New South Wales Royal Commission.

Fayol built a pile of freshly mined Commentry slack coal, 40 metres long and varying in height from 6 metres to nothing. The pile was 1 metre

<sup>1</sup> "Etudes sur l'altération et la combustion spontanée de la houille exposée à l'air"—Bull. Soc. Industrie Minérale, Second Series, Vol. 8, 3rd part. 1879.

wide at the top. The temperatures were taken daily at eleven different points in the pile; the atmospheric temperature was also recorded. Fig. 3

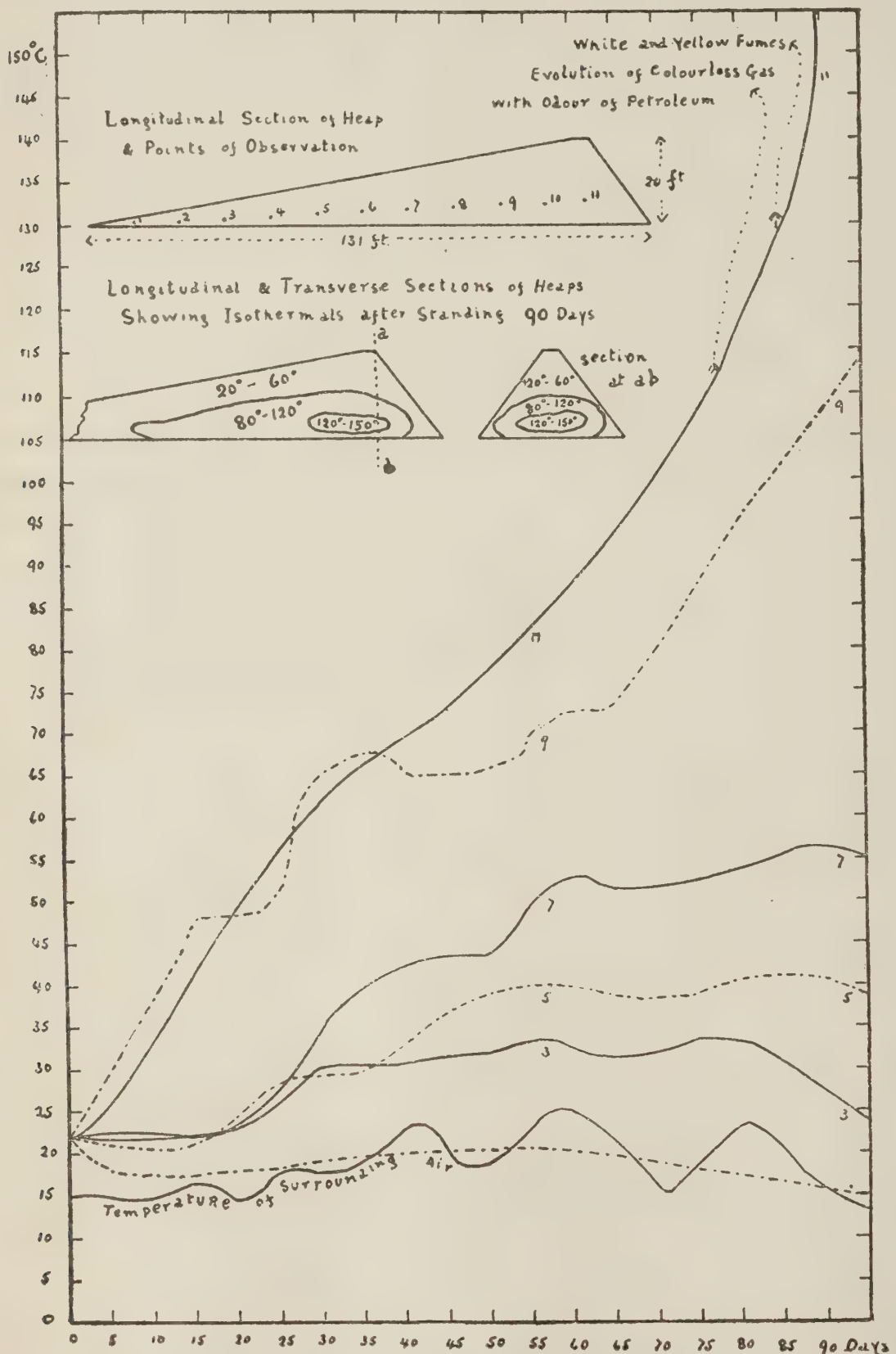


Fig. 3. Curves showing temperatures in coal pile.

shows: a section of the pile with the points of observation marked, the curves plotted from the daily temperature readings, for 90 days, at six of the

eleven points (the curves at the alternate points are left out to avoid confusion); the curve of the atmospheric temperature over the same period; and longitudinal and cross sections of the pile at the end of 90 days with isothermal curves plotted.

The curves show that rise of temperature increases with the height of the heap, and that the highest temperature occurs directly under the highest part of the heap and near the ground. In the thinnest part of the heap the coal rapidly cools from its original temperature and afterwards approximates to atmospheric temperature. Towards a height of 3 or 4 metres the temperature rises for a while and then falls again without ever passing  $60^{\circ}$  or  $70^{\circ}$  C. Where the heap is 4 metres high or over, the temperature continues to rise and ultimately the pile fires.

Fayol says: "From whatever part of the mine it comes, whatever may be its ash content, or the nature of the ash, coal piled up in the air heats in approximately the same manner and appears in its heating to follow laws which are approximately constant. Atmospheric influences—cold or heat, drought or damp—have not been sufficiently marked to be sensible."

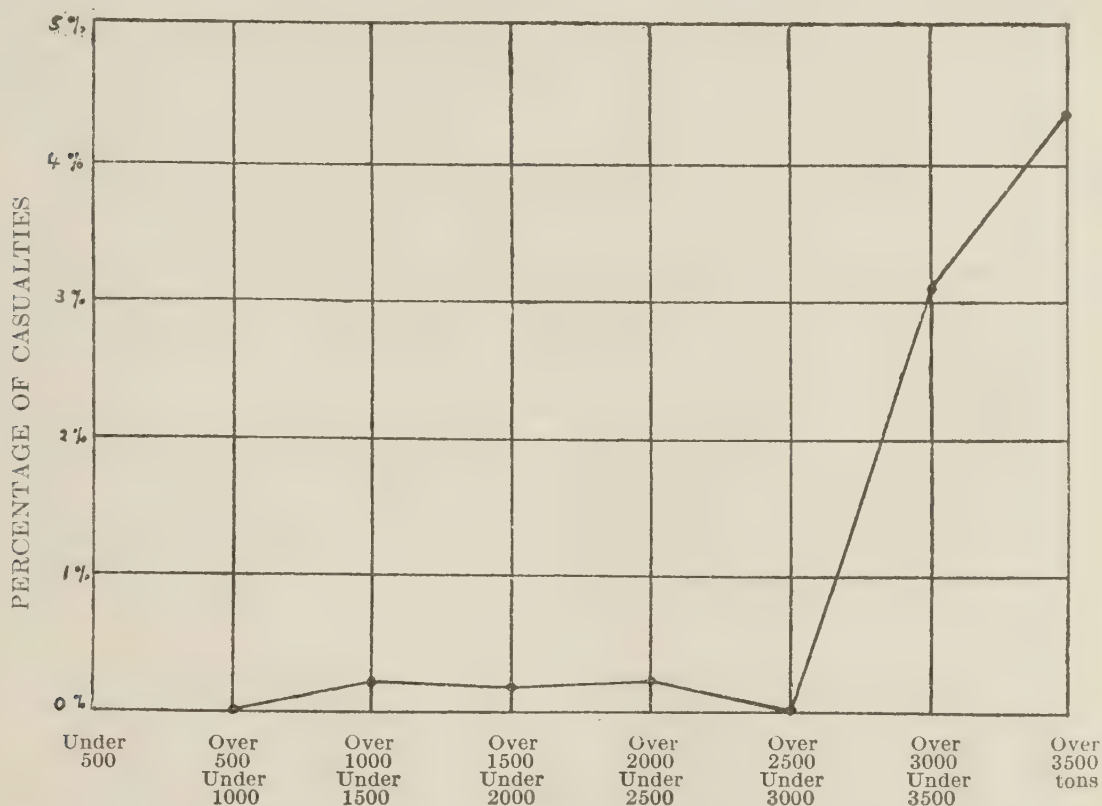


Fig. 4. Curve showing relation between size of coal cargoes and liability to fire.

With Commentry slack coal no spontaneous combustion has occurred with heaps of less than  $6\frac{1}{2}$  feet high; but where the height exceeds 13 feet, spontaneous combustion nearly always occurs. This fact, that there is a danger height for any coal, above which it is not safe to build a pile of that coal, has been repeatedly confirmed.

The New South Wales Commission have shown this same point, of increase of danger with increase of size of pile, in a quite different way.

They have collected statistics of 2,149 shipments of coal, 13 of which fired or heated. Fig. 4 is a curve which shows the percentage of casualties plotted against the size of the cargoes. It is quite clear from this curve that with the coal and under the conditions that these ships were loaded, the danger of heating or firing increases very rapidly when the cargo exceeds 3,000 tons.

(e) The danger of an initial high temperature was first established by the New South Wales Commission. Their attention being directed to the epidemic of casualties during the hot summer of 1895-6, they were able to show clearly from their data that spontaneous fires in cargoes were associated with high maximum temperatures.

Prof. Threlfall has prepared, from data presented to the British Royal Commission of 1876, by E. Cooper Rundell, the curves shown in Fig. 5. The full curve shows the casualties from fire or heating for all ports of the United Kingdom, and for each month of the year, expressed as percentages of shipments of 500 tons of coal and upwards on voyages across the equator and through the Suez canal. The figures from which the curve is plotted cover a period of 3 years and are for 4,898 shipments with 102 casualties. The dotted curve shows the mean temperature throughout the year.

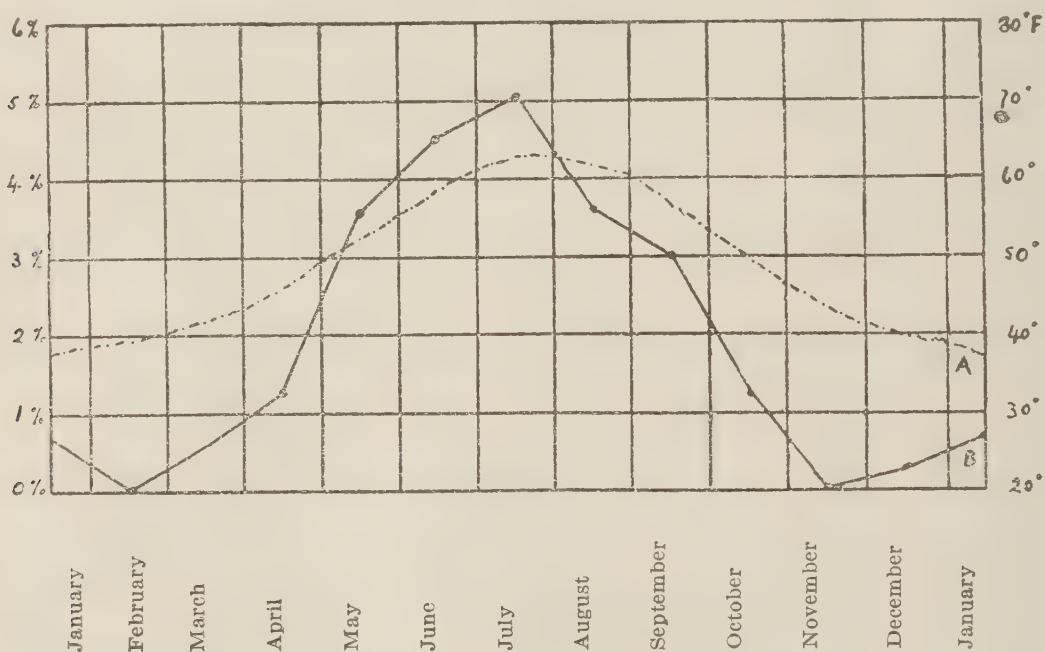


Fig. 5. Curve showing relation between time of lading of coal cargoes and liability to fire.

The intimate relation between the percentage of casualties and the temperature at the time of loading is beyond doubt.

It is not so easy to prove the same fact with regard to piles of coal on land. A coal pile is usually built gradually and with no record of dates or temperatures. The writer's attention was called to a coal pile which had heated rather rapidly, but which, having been built (in Canada) towards the end of September or the beginning of October, might have been supposed to have been cool to start with. Inquiries, however, had elicited

the fact that the coal was observed to be warm when unloaded from the steamer (estimated at 90° F.) although this had not been reported at the time.

One experiment by H. Fayol may be cited in this connexion. He showed that by heating the coal to a high initial temperature, which was yet well below its ignition point, it was quite easy to produce spontaneous combustion even in small piles of coal. This is perhaps the most conclusive experiment that has yet been made as to the influence of air on the spontaneous combustion of coal.

He made a conical heap of coal, containing from 70 to 100 cubic feet of coal, on the ground, surrounded with a ditch which could be filled with water. A cover was put over the coal, large enough to surround the heap and fit into the ditch, in such a way that the heap could be hermetically sealed from the external air. In one experiment the coal was heated to about 100° C. to start with. The cover was left in position, but some air holes with which it was provided were opened and shut and the temperature variations observed. When the holes were open the temperature rose, when they were closed it fell. By leaving the holes open for two days spontaneous combustion resulted; the fire was put out by closing the holes and allowing the temperature to fall to 60° C.

Very little is known of the actual chemical compounds to be found in coal, although a great deal of work has been done on the decomposition products of coal when heated. Coal has been treated with acids, alkalies, ether, alcohol, pyridine and other solvents, and the extracts examined; but the results achieved have not been very great as yet. It is certain, however, that many coals contain unsaturated hydrocarbons and aldehydes, substances that are readily oxidized, the oxygen being added on to the molecule and not resulting in the formation or splitting off of carbon dioxide or water. Unsaturated compounds are detected by their power of absorbing bromine, as in Prof. Fischer's test described above. Aldehydes when oxidized produce acids; organic acids have been shown to be produced by the weathering of coal.

Although a great deal of work has been done on the weathering of coal the results are very difficult to summarize, classify, or discuss. Coals of all ages and qualities have been used and the weathering has proceeded under such variable and often uncertain conditions that very little can be deduced.

The chemical changes taking place in coal when oxygen is absorbed are easier to follow when proceeding more rapidly, that is, at higher temperatures. Dr. Richters of Waldenburg<sup>1</sup> heated 2 grams of a coking coal to 190° C. for 10 hours in a current of dry, carbon dioxide free air, and collected and weighed any water or carbon dioxide produced. He found that the coal gained 4.21 per cent in weight. The analysis of the coal before and after heating is shown in Table XXIV.

<sup>1</sup>Dingler's Poly. Journal, Vol. 190, p. 398, Dec., 1868. Translations of several of Richters' papers are given in the Report of the New South Wales Commission.

TABLE XXIV

Coal dried in desiccator.	Heated coal.	104.21 parts by weight of the heated coal, containing, consequently
		parts
Carbon.....86.82	82.19	85.65
Hydrogen.....4.26	3.38	3.52
Oxygen (and Nitrogen).....6.40	11.96	12.47
Ash.....2.52	2.47	2.57
Total.....100.00	100.00	104.21

The coal accordingly lost by heating 0.74 per cent of hydrogen and 1.17 per cent of carbon, but gained 6.07 per cent oxygen. The water produced, however, corresponded to 0.66 per cent hydrogen, and the carbon dioxide to 1.25 per cent carbon. The result of the experiment is, therefore, to show that by heating the coal in air there is complete oxidation of the hydrogen and carbon which it loses.

Dr. Richters also showed that coal would absorb carbon dioxide as well as oxygen, and that its behaviour towards oxygen was materially changed by the absorption of carbon dioxide.

H. Fayol has done similar work on the oxidation of heated coal. He

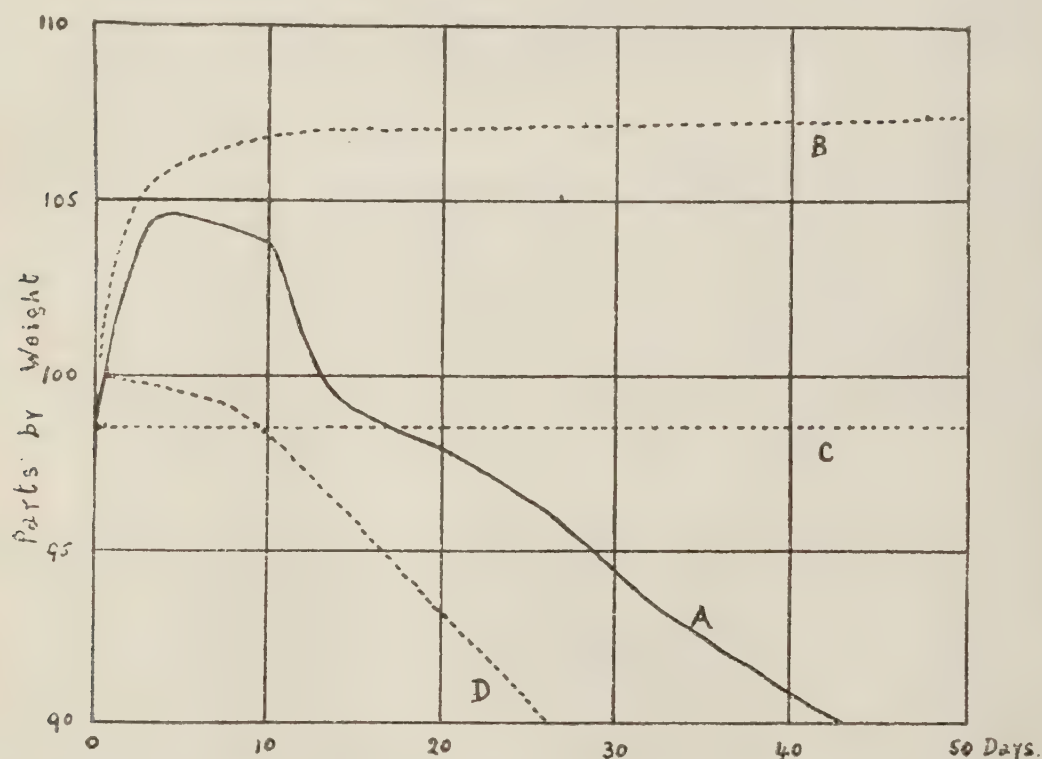


Fig. 6. Curves showing components of variations of weight of heated coal.

Components of the curve of variations of weight of Commentry coal, in powder, exposed to air at 200°C.

A=Curve of variations of weight, as observed.  
 B= " " " " " " due to absorption of oxygen.  
 C= " " " " " " due to loss of hygrometric water.  
 D= " " " " " " due to loss by slow combustion.

continued the heating for a longer period and analysed the curve of variation of weight into its separate components. Some of his results are shown in Fig. 6.

TABLE XXV

EXPERIMENTAL	BEDSON (1)		TROW- BRIDGE (2)	PARR AND BAKER (3)					
	A	A	B	C	C	D	D	E	E
Coal									
Age of coal	Freshly hewn	Several months	?	Fresh drillings	Face sample 2 years	Fresh drillings	Face sample 2 years	Fresh drillings	Face sample 2 years
Weight of coal tested . . . . . grams	?	?	296	261	209	220	205	231	108

## PART I.—LAST PORTION OF AIR IN EXHAUSTION OF VESSEL

Time coal stood in vessel after closing and before exhausting, days		?	7	9	14	2	7	1
C.C. of gas per 100 grams coal	—	7.4	54.2	46.2	87.4	16.4	85.5	35.7
Composition of gas—								
Methane.....%	Air of vessel was displaced by mercury before commencing the evacuation.	16.1	22.53	.....	21.79	.....	23.17	.....
Carbon dioxide.....%		3.0	3.92	4.15	3.86	7.80	12.09	.....
Oxygen.....%		22.5	5.30	4.46	1.04	15.50	1.11	22.20
Nitrogen.....%		58.4	63.25	91.39	73.31	76.70	63.63	77.89
C.C. of oxygen + nitrogen per 100 grams coal.....		6.0	39.9	44.3	65.0	15.1	55.4	35.7
Deficiency of oxygen as % of O+N compared with 21.0% in air		-6.8	+13.8	+16.3	+19.6	+4.2	+19.3	-1.2

## PART II.—GAS REMOVED BY VACUUM.

Time coal stood in exhausted vessel for gases to be evolved, days.....	Two fractions.			16	13	8	12	10	13	10
	5	17	30							
C.C. of gas per 100 grams of coal	18	14.5	16.2	21.3	10.31	7.12	22.18	1.08	11.26	1.02
Composition of gas—										
Methane.....%	41.60	3.58	4.52	53.4	59.59		86.37		19.26	
Carbon dioxide.....%	1.65	1.18	0.64	7.0	17.85	80.50	7.58		32.09	54.60
Carbon monoxide.....%				0.7						
Oxygen.....%	8.99	23.80	20.91	3.2	4.83	1.30	0.61		7.32	9.90
Nitrogen.....%	44.76	71.44	73.93	35.7	17.73	18.20	5.44		41.33	35.50
C.C. of oxygen + nitrogen per 100 grams coal.....	9.7	13.8	15.4	8.3	2.33	1.39	1.34		5.58	0.46
Deficiency of oxygen as % of O+N com- pared with 21.0% in air	+4.3	-4.0	-1.0	+12.8	0.4	+14.3	+10.9		+6.0	-0.8

(1) "The Gases enclosed in Coal and Coal Dust," by P. P. Bedson, Trans. Inst. M. E., 1902, Vol. XXIV, p. 27.

(2) "The Gases enclosed in Coal and Certain Coal Dusts," by F. G. Trowbridge, J.S.C.I., 1906, Vol. XXV, p. 1129.

(3) "The Occluded Gases in Coal," by S. W. Parr and P. Barker, Bulletin 32, University of Illinois Engineering Experiment Station.



He finds that when coal is first heated in the air to 200° C. it rapidly loses its hygroscopic water; it also absorbs oxygen, thus increasing in weight, rapidly at first but more slowly after a while; but it also loses weight owing to slow combustion with the evolution of carbon dioxide and water; this is very slow at first but after about five days becomes quite rapid. The net result of these different changes is shown by the full curve: the coal first rapidly loses weight (to the extent of its water content) and then gains weight fairly rapidly for two or three days; it then loses weight very slowly for about seven days after which the loss of weight becomes quite rapid.

All these reactions which take place at high temperatures, in all probability also take place at ordinary temperatures, although much more slowly.

No figures showing the actual relation between the oxygen absorbed and the heat evolved seem to be available for any coal.

The oxidation of coal, as illustrated above by the work of Richters, Fayol, and Haldane and Meachem, might seem to be amply sufficient to explain the phenomena of weathering and spontaneous combustion. In spite of this, whether justified or not, there is a wide-spread opinion that some extra cause must be found to explain the firing of coal. Some writers appear to think that this extra cause must in itself be sufficient to heat the coal to its ignition point. This is a most improbable theory; it is far more likely that it is only necessary for the coal to be heated up to some temperature where it is still well below its ignition point, but where the oxidation of the coal becomes sufficiently rapid to ultimately heat the coal up to the ignition point.

Several different ways in which coal may receive an initial heating will now be considered.

(1) *Occlusion*. It is found that the metal palladium can absorb at ordinary temperature and pressure nearly 900 times its own volume of hydrogen. This gas does not appear to form an actual chemical compound with the palladium, but rather to be dissolved in it or possibly condensed on its surface; it is said to be occluded. When a gas becomes occluded heat is often given out.

Charcoal can occlude large quantities of many gases; the quantity of gas absorbed increases with the pressure and is approximately proportional to it. The quantity of heat given out during the occlusion nearly approaches that set free on dissolving the gas or by its passing into a liquid condition. Cocoanut charcoal, for example, will absorb nearly 100 volumes of carbon dioxide at ordinary temperature and pressure, about 150 calories of heat being generated for every gram of gas absorbed.

Freshly prepared charcoal that has been cooled in absence of air, is very liable to spontaneous ignition if exposed in large piles, this being due to the heat generated by the occlusion of the oxygen and nitrogen of the air. The actual oxidation of the carbon is probably negligibly small until a high temperature is reached. Here, therefore, is a case where the carbon is actually heated up to its ignition point by the heat of occlusion of gases.

Coal contains a high percentage of carbon, but that is probably all in the combined state. Coal certainly does not occlude gases to anything like the extent to which any of the common forms of charcoal do.

A large number of analyses have been made of gases extracted from coal, but the experiments are hardly conclusive.

When coal is first exposed during the working of a mine, hydrocarbons are always evolved, sometimes to a very great extent; this evolution often goes on for a considerable time and with a consequent reduction of the calorific value of the coal. There is no proof, however, that these gases were not mechanically enclosed under great pressure in the pores of the coal, whence they escape when the pressure is reduced. When the coal is exposed to the air, besides losing hydrocarbons, it absorbs oxygen and nitrogen, the proportion of the former being greater than in air. This absorption may be merely a diffusion of the air into the pores of the coal together with an oxidation of the coal by means of the extra oxygen. If this coal is now placed in a vessel and the gases pumped out, oxygen, nitrogen, hydrocarbons, etc., are obtained.

The crucial method of distinguishing between gas mechanically enclosed in the pores and occluded gas is that gas mechanically enclosed cannot occupy a greater volume, under the pressure at which it was enclosed, than that of the pores it occupies, whereas occluded gases can occupy a greater volume, for example, palladium, as mentioned above, occludes many hundred times its own volume of hydrogen.

We cannot test the way the hydrocarbons referred to above are held in the coal, as we have no means of knowing the pressure to which they have been subjected.

A few examples of gases extracted from coal, at ordinary temperatures, are given in Table XXV. These figures show that the total volume of oxygen and nitrogen known to be extracted from the coal is so small that it leaves the question as to whether the gases were occluded or mechanically enclosed uncertain. The difficulty of separating the gas out of the coal from the air in the containing vessel makes it impossible to even determine the volume of the former, unless the vessel is filled with water or mercury before beginning the extraction.

The large quantity of methane in fresh coal and the small amount left in coal that has been exposed to the air for some time is clearly shown in the table.

Bedson and, working under his direction, Trowbridge, frequently find the proportion of oxygen to nitrogen in the gas extracted from coal to be greater than in air; this would appear to be strong evidence for Bedson's claim that oxygen and possibly nitrogen, but proportionately more oxygen, were actually occluded by the coal.

Most experimenters, in all but a few of their experiments, find the proportion of oxygen in the gases extracted to be less than in air. As oxygen is known to be comparatively readily taken into combination by

the coal, this deficiency does not necessarily disprove Bedson's statement, rather the claim is confirmed by the fact that an excess of oxygen is occasionally found. If oxygen is occluded, and to an extent compared with nitrogen relatively greater than in its occurrence in air, the experiments just cited indicate that in the majority of cases the occluded oxygen combines with the coal so rapidly that there is a deficiency of oxygen in the gas which can be pumped out again.

The nitrogen is always in excess over the oxygen if the coal is heated before the gases are pumped out, oxidation being much more rapid at higher temperatures.

The conclusion arrived at, from the above discussion of evidence, is that the quantity of air occluded by coal is so small that the actual heat of occlusion cannot be important; but a secondary action must be considered in which the occluded oxygen is probably no longer negligible.

(2) *Oxidation Accelerated by Occlusion.* When two or more gases are occluded in the same substance, they are brought into such intimate contact with each other that they may combine with notable rapidity, although if they were mixed in the gaseous state combination would be inappreciable. Platinum black, gas and pipe lighters are well known examples of this type of reaction. The platinum black exposed to the air occludes oxygen; when it is brought into an atmosphere of coal gas or alcohol vapour these latter are also occluded, and coming into very intimate contact with the oxygen they are oxidized with such rapidity that heat is generated faster than it can be dissipated and the temperature rises to the ignition point.

Charcoal that has been heated to remove occluded gases and allowed to cool in an atmosphere of hydrogen sulphide, catches fire when placed in an atmosphere of oxygen. The oxygen combines with the previously occluded hydrogen sulphide, although if the gases be mixed under ordinary conditions no appreciable action results.

Freshly mined coal may be compared with the charcoal described above. The coal is saturated with hydrocarbons instead of with hydrogen sulphide, and exposed to the air instead of to oxygen; it is quite natural to expect that in this case also an accelerated oxidation will take place which, once begun, may easily result ultimately in the firing of the pile. Even if the coal has lost all its gaseous hydrocarbons, the occluded oxygen will be brought into such intimate contact with the readily oxidizable constituents of the coal that the same result will be reached.

Coal occludes gases to so small an extent that the action described above is not likely to heat it up to its ignition point, but may provide the initial heating for which we have been looking. For reasons already given, open combustion will result only in a large pile.

(3) *Oxidation of Pyrites.* That the spontaneous firing of coal is due to the heat generated by the weathering of the pyrites it contained, was one of the first theories advanced, and it is still widely held. Experts such as

Lewes and Threlfall now vigorously combat the idea that the pyrites do more than slightly assist.

The arguments brought forward by the two sides are somewhat as follows:—

Nearly all coal contains pyrites.

Pyrites is known to be oxidized by the air in the presence of moisture, heat being thereby generated. The reaction may be written as follows:  $2\text{FeS}_2 + 2\text{H}_2\text{O} + 7\text{O}_2 = 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4$ , although it is probable that the reaction proceeds partially or altogether to the formation of ferric sulphate or basic sulphates. The pyrites may also decompose in such a way as to liberate sulphur.

The above reaction requires water, and wet coal is commonly supposed to be much more liable to fire than dry coal.

Coal mine waters often contain notable quantities of sulphuric acid, thus proving the weathering of the pyrites.

Coal heaps that have been exposed to the weather often have visible lumps of basic ferric sulphate, and ventilation holes in such piles are said to sometimes become choked up with the free sulphur deposited in them.

On the contrary, there does not appear to be any connexion between the amount of pyrites in a coal and its tendency to fire.

Laboratory experiments on the oxidation of coal show that coal takes up oxygen as well or better when dry than wet, which is the reverse of what would be the case if the pyrites was being oxidized, and that the amount of oxygen taken up is often greater than could theoretically be taken up by the complete oxidation of all the pyrites present.

Fires are frequently known to have originated in dry coal.

The heat of oxidation of pyrites is only small, weight for weight coal will evolve about four or five times as much heat by its complete oxidation. A more conclusive statement would be that a given weight of oxygen evolved more heat by combining with the readily oxidizable constituents of coal than by combining with the pyrites. This is probably true, but the writer is unacquainted with any work which has been done that would prove it.

Pyrites, by weathering, could hardly heat itself up to ignition point, much less the coal surrounding it; in fact, heaps of pyrites free from carbonaceous material are never known to fire spontaneously.

Prof. Lewes said that as pyrites can liberate sulphur, the ignition point of which is lower than that of coal, he at first thought that pyrites might cause danger by thus lowering the ignition point. He found, however, that sulphur oxidizes faster than it could be liberated, even at temperatures as low as  $60^\circ \text{C}$ ., so that this danger cannot exist.

In considering these arguments we must remember that there are different varieties of pyrites, that known as marcasite weathering much more rapidly than the ordinary variety. The fine flakes of pyrites, some-

times scattered throughout the coal, are probably marcasite and certainly weather faster than the larger lumps.

A single match may ignite a pile of shavings, a single flake of marcasite might cause a warm spot that might result in a coal pile firing. This might explain the fact that the tendency for a coal pile to fire is not proportional to the percentage of sulphur or pyrites present.

We are not at present looking for something to heat the coal to its ignition point, but only to give it a little initial heating. If sulphur is liberated from pyrites and oxidizes (both actions being accompanied by an evolution of heat) at low temperatures, it might easily act as a starter, although the sulphur did not remain as such to lower the ignition point.

The crucial question seems to be, does the coal or the pyrites generate heat the faster by its normal oxidation at low temperatures? The evidence seems to be strongly in favour of the answer: the coal. This would thus rule pyrites out of account as the usual cause of fires. It is, of course, always conceivable that under certain circumstances this might be reversed and the pyrites blamed; but this probably seldom or never occurs.

On one point all parties are agreed. When flakes of pyrites weather they expand and fracture the coal, and thus expose more and fresh surfaces for oxidation and indirectly increase the danger of heating. As a general rule, however, this breaking must be slight compared with that caused by handling, although it will certainly assist in the deterioration of the coal.

(4) *The Action of Water.* This is an even more knotty point than the preceding one. On the one hand we have scientific evidence to prove that coal oxidizes less when wet than when dry, and on the other an almost universal and deep-rooted opinion, amongst men of practical experience of the storage of coal, that wet coal is dangerous.

The scientific experiments of Richters and others must carry conviction as far as they go; at the same time it appears dangerous to assume, without the very fullest proof, that the opinions of the practical men are simply the relics of an old superstition, bolstered by forgetting facts that appear to contradict and only remembering confirmatory facts.

A British Royal Commission on coal investigated this problem in 1876. The Commissioners said: "Most of the witnesses who have come before us have strongly condemned the shipment or carriage of coal in a wet condition, and their experience in this respect is, to a certain extent, supported by the scientific evidence. . . . It would appear that the wetting of certain kinds of coal, more especially those containing pyrites, is active in promoting spontaneous combustion; but the statements of some of the witnesses lead to the impression that moisture has been credited with cases of combustion beyond the sphere of its operation; while from other passages of the evidence, it appears to us that the influence of the water, existing to a greater or less extent, in all coal before it has been brought to the surface, has not been sufficiently recognized."

The two scientific experts of the Commission, Dr. Percy and Professor

Abel, said, "Spontaneous ignition of coal, when due to the oxidation of the porous and readily oxidizable carbonaceous substances occurring in coal, does not appear to be favoured by the presence of water in the coal or by its access to a cargo; on the contrary, these portions by becoming wet, would have their pores more or less filled with water, and their power of absorbing oxygen would be proportionally diminished, hence the presence of water must be antagonistic to the action of the latter in many instances, though, when iron pyrites is present, it may promote or accelerate spontaneous heating, as already pointed out."

In spite of the quotations above, the report of the Royal Commission of 1876 seems to have been taken as condemning the shipment of all wet coal. The King's Regulations and Admiralty Instructions, Article 523, paragraph 25, read: "Coal should not be taken on board wet, as moisture sometimes causes a rapid and dangerous generation of heat and gas. . . . Coal should always be kept as dry as possible." This paragraph has, however, since been rescinded.

The New South Wales Royal Commissioners stated in their Report of 1897 that: "It must still be regarded as an open question, however, whether the heating of Newcastle coal is in any way dependent on the amount of moisture which it contains. On the one hand, we have the very definite experimental result of Fayol that moisture has no influence whatever on the liability to spontaneous combustion of the coals of Commentry, and, on the other, we see that the disintegrating action of oxidizing pyrites may have an indirect effect."

It may here be stated that the effect of water in disintegrating pyritic coal is always conceded, although many persons hold that except with highly pyritic coal it is not very important.

The N.S.W. Commission after making the first report, carried out a further investigation to determine the effect of water upon stored coal. Two large wooden bins were built and both filled with slack coal under as nearly identical conditions as possible except that in filling the one the coal was kept dry and in the other was thoroughly wet during loading by water from a hose. The wet coal was found to be 10° C. cooler to start with, and, although it heated slightly at first, after 46 days the mean temperature in this bin showed a steady decline that continued until the 139th day, when the temperature readings were discontinued. The dry coal, on the contrary, grew steadily, although at first slowly, hotter, and after 63 days the bin had to be flooded and the heated coal dug out in order to avoid a fire.

The 1900 report says that to the question the Commission set out to solve, therefore, they return "a direct and unconditioned answer. Coal is less liable to spontaneous combustion when it is loaded wet than when it is loaded dry."

The report disposes of the findings of the 1876 Commission as follows: "The British Commission received 26 answers to the effect that wet coal was the more dangerous. But an analysis of the evidence discloses

that 25 of these answers were based on 'general impression' or hearsay evidence only, while the 26th was not tested by cross examination. The opinions referred to were held, not by scientific men, but by those engaged in the coal trade. . . . All such views, it seems to us, must now be definitely abandoned."

A case in confirmation of these views is that of the sailing ship *Strathdon* which sailed with coal from Newcastle, N.S.W., on June 16, 1900, arriving at San Francisco on August 25. It rained very hard whilst some of the coal was above ground awaiting shipment, and the coal became so thoroughly wet that water ran out of the trucks during loading; this wet coal was charged into holds 2 and 3, whereas holds 1 and 4 were filled with perfectly dry coal. The holds were 23·6 feet deep, temperature tubes 22 feet long were inserted into the body of the cargo through the hatchways and the temperatures were regularly taken and recorded in the log-book. The air temperatures were 62° F. at start, 92° at the equator, and 72° at discharge. In the dry holds the temperatures were 74° F. at start, rising to 94° and 92°, and falling to 94° and 84° at discharge; in the wet coal the corresponding temperatures were 62° F., maximum 77° and falling to 74° and 75° at discharge. The maximum temperature difference was 22° F. and the average 13·8° F., the wet coal being the cooler.

On the other hand, V. B. Lewes cites the case of a ship carrying a cargo of coal, where the main hatch was filled in dry weather and the after hatch whilst it was raining. After a few days the temperature was about 10° F. higher in wet coal than in the dry, spontaneous ignition being the ultimate result.

Prof. Lewes' opinion is that at first external wetting retards the absorption of oxygen, but that the presence of moisture afterwards accelerates the action of the already absorbed oxygen upon the hydrocarbons; he draws a sharp distinction between wet coal and damp coal, it being the latter that he considers dangerous.

Enough has now been said to show the complexity of the subject. Before proceeding further with its discussion it will be well to define what is meant by dry coal. Coal as taken from the mine, or that has been exposed to rain, contains water that it gives up when exposed to dry air; when it no longer loses weight it is said to be "air dry." If air dry coal is ground up and subjected in a thin layer to a temperature of 105° C. for one hour, it loses a further quantity of water and is now said to be "dry." This definition of dry coal is quite empirical, it would be very rash to assume that the coal is free from water, it certainly contains the elements of water and can readily be made to give up actual water. Dry coal, in questions of handling and storage, usually means air dry coal.

It is probable that water was first blamed for the spontaneous ignition of coal, on account of a false analogy with the heat produced by the fermentation of damp hay. Further, it is sometimes noticed that the top of a coal pile feels warm the day after a shower of rain. The obvious explana-

tion of this is not that the water causes the coal to heat, but is, as suggested by the New South Wales Commission, that the pile was already hot inside; the water trickling down came to the hot coal, was turned to steam, and rose to the surface where its warmth was felt.

It is often pointed out that many chemical reactions that take place readily or even violently under ordinary conditions, will not take place at all if the reacting bodies are exceedingly dry. This is no argument, however, in favour of the danger of storing wet coal. The amount of water needed for such reactions is so very small that certainly all air dry coals, and probably all dry coals, contain far more than is necessary for any chemical action in which water is merely an accelerator and is not one of the reacting bodies, as in the weathering of pyrites.

Richters has carried out experiments upon the rates of oxidation of damp and of air dry coal. He showed that not only does the air dry coal absorb oxygen faster than the damp coal, but by putting some calcium chloride into the vicinity of the former, so that it becomes still dryer, its rate of oxygen absorption is further increased.

Coal immersed in water, being practically protected from the oxygen of the air, is subject to little or no deterioration. It was, therefore, natural to expect that wet coal would also be considerably protected from oxidation, but there was the possibility that damp coal might be worse than either wet or dry coal. Richters' results, if generally true, clearly show that this is not the case, dry coal being most readily oxidized. Experiments are being carried out to test this point by the University of Illinois (see Bulletin 17) and the University of Missouri (see Bulletin 1). The results of their work, which is not yet completed, can so far hardly be said to confirm or disprove Richters' conclusions.

The writer's own opinion is that water always retards the oxidation of coal, except in its effect on pyrites, but that indirectly it may have a marked influence for good or for bad on the condition of stored coal. Some of these ways in which the coal is influenced are well known, others are here put forward as tentative suggestions.

(a) Fayol has stated that by building up a coal pile in thin layers, allowing sufficient time for the first rapid oxidation of each layer of coal to take place whilst the heat generated can be easily dissipated into the air, before covering with another layer, a coal pile can be safely built to any height. Generally coal will be partially oxidized before storing and the danger thus be reduced; but if coal is taken wet from the mine, or is wet soon after mining, and is stored still wet, this preliminary oxidation is largely prevented. The coal afterwards dries out and the first most rapid and energetic oxidation takes place in the pile where the heat accumulates and danger results.

(b) A warm coal thoroughly wet by rain or by deliberate spraying will be cooled by the water itself and also by its subsequent evaporation. The coal is thus, as in the New South Wales bin experiment, cooler than it

would have been dry and the initial temperature being lowered the danger is reduced.

(c) It has already been stated that in coal cargoes fires almost always begin in the cone under the hatchway where the small broken coal accumulates and where there is consequently the largest proportion of surface exposed for oxidation. When dry coal is dumped there is the same tendency for the small coal to settle into a compact mass towards the bottom where, unless it is too compact to allow the air to circulate, there will be similarly the greatest danger of heating. When coal is wet the dust and small particles cling together and adhere to the larger lumps, so that a pile built of wet coal is likely to be more homogeneous from top to bottom. This difference in the mechanical distribution of the coal may easily make a great difference to its tendency to fire; it is possible that in some cases the danger is thereby increased and in other cases decreased.

(d) After a pile has been built, if it is exposed to heavy rain the dust and fine coal are washed down and form a dense layer 1 or 2 feet below the surface. This also must have a great effect on the air circulation through the pile and consequently on its tendency to fire. If the circulation was previously too rapid for serious heating, the danger will be increased; if too slow, it will be made still slower and the danger of ignition will be decreased.

If these views are correct, water is a preservative for all coal except the pyritic, but that wetting the coal before or after storing may do much good or may do much harm. It is probable that when our knowledge of the air circulation and rate of oxidation in coal piles is increased, water will be a good servant; at present it is a dangerous ally.

(5.) *Heat of Oxidation of Bituminous Shales.*—Bituminous shales from the coal seams often fire as easily, possibly more easily, than the coal itself. It is said that in cases of trouble with Cape Breton coal in Montreal, a piece of shale is usually found in the centre of the heated portion; but this may be merely a coincidence. The problem yet to be solved is—does the pure coal or the shale oxidize and evolve heat the faster at ordinary temperatures.

(6.) *External Heat.*—The initial heating may be the result of boilers, steam pipes, or flues near to the coal, or of cotton waste, which if soaked in some oils oxidizes readily, and which if allowed thus to get into a coal pile might easily cause a hot spot. Again, where wood comes in contact with coal it is often noticed that the fires begin in close proximity to the wood. This may be due to heat evolved by the rotting of the wood or to some modification of the air currents caused by the wood.

(7.) *Heat of the Sun.*—It has been shown above that the hotter the coal when stored the greater is the danger, coal being black absorbs the sun's rays readily and may easily reach a temperature considerably above the shade temperature at the time. If coal when on a car before dumping, or on the surface of a pile, becomes heated by the sun, and if the warm portion

is then buried under more coal, a fire may easily result. This appears to be a case where a judicious spraying with water would prove a safeguard.

The New South Wales Commission made some experiments and found that on seven successive days the maximum temperature 3" or 4" below the surface of some coal exposed to the sun varied from 25.6° F. to 36.8° F. higher than the maximum shade temperature on the same days.

It seems to be doubtful whether most coal piles are prevented from firing by an excess or a deficiency of air. Fires in ships begin under the hatchways where, it is true, the most air might be expected, but they begin in the cone of fine coal where the circulation can only be slight. The remedy would, therefore, seem to be to increase the ventilation; but, on the contrary, this is found in practice to be the worst thing to do. Fires in coal piles generally begin near the bottom away from the air, and yet again ventilation is said to be dangerous. Thorough ventilation would certainly prevent fires in either case.

V. B. Lewes says that for ventilation to do any good, cool air would have to flow continuously and freely through every portion of the coal. Steam coal, he says, will absorb twice its own volume of oxygen in ten days under favourable conditions. A ton of such coal occupies 42 or 43 cubic feet, of which 12 cubic feet is air space, a ton will, therefore, absorb 60 cubic feet of oxygen in ten days, which represents 300 cubic feet of air or 25 times the volume of the air contained in it; that is to say, if these figures are correct, there would have to be a complete change of air every ten hours.

It is difficult to understand how air can circulate through a large pile of slack coal, it looks to be almost impossible. The air does not appear to come in through the sides of the pile as fires occur indiscriminately near the sides or in the centre and their position is not apparently affected by the direction of the wind. One possible explanation is that inequalities of temperatures in the pile cause convection currents, air descending from the top in some places and ascending in others. Two or three somewhat casual inspections of a large pile ventilated with a large number of vertical holes passing from top to bottom, failed to anywhere discover a down draught, warm air appeared to rise from all the holes, and in winter when the pile was covered with snow melted passages through to the surface.

Gaseous diffusion must always cause a circulation of air through a coal pile; but as oxygen, which is denser than nitrogen, is absorbed by the coal the residual air inside the pile becomes lighter than that outside and the normal rate of diffusion is thereby accelerated. Changes of barometric pressure will also effect a slight air circulation through a pile; when the pressure is low not only will the air in the interstices expand, but air dissolved in water in the coal, and occluded gases, will also be given off, since the amount of gases dissolved or occluded is proportional to the pressure; when the pressure increases there will be a flow of air back into the coal to fill up interstices, to dissolve in the water and to be occluded. The amount

of such air currents up and down will be greatest at the surface and decrease steadily downwards; the circulation best suited to cause fires might, therefore, be expected to occur at a depth proportional to the height of the pile: as a matter of fact, fires usually occur about two-thirds of the way down. We have so far assumed that the ground on which the pile rests is impervious, but if it is a light sandy soil the surging of the air up and down with barometric changes will take place not only through the pile but also through some of the soil below. The amount of air passing through the coal from this cause will be thus increased, and, together with the air circulated by other causes, may be too great to cause a fire even at the very bottom of the pile. This idea is in accordance with the fact that coal piles give more trouble on wet clayey soil than on dry sandy soil, but it has been suggested to the writer that the rising and falling of surface moisture in the soil are more likely than barometric changes to cause a cooling air circulation through the coal. Those who believe in the theory that wet coal is dangerous say that coal fires on a clayey soil because it remains damp owing to the poor drainage.

Whatever the explanation, it at any rate appears certain that it is well to store coal on well drained ground; a thick bed of cinders is often used as a foundation.

It is just possible that some coals contain enough occluded oxygen when stored to allow a considerable amount of oxidation to take place without any access of fresh air. Parr and Hamilton<sup>1</sup> find that samples of coal deteriorate in even the most carefully sealed containers. They examined some coal that had been unopened in an air-tight jar for three years, a lot of the pyrites was found to be oxidized to ferric sulphate, this was leached out and determined, and it was found that the oxidation which had been accomplished corresponded to 1.99 grams, or 1.39 litres, of oxygen, equivalent to 7 litres of air. The coal was buckwheat size, filling a pint jar three-fourths full. This result is hard to understand when compared for example with Parr's own figures showing the small amount of oxygen occluded in coal; but it is possible that the iron pyrites was oxidized at the expense of oxygen compounds in the coal. Details of the experiment are not given—if water containing dissolved air was used, or if the coal was occasionally allowed to come into contact with the air during the leaching process, it is possible that much of the recorded oxidation took place during the leaching process and not in the bottle.

Fayol's experiment described on page 105 does not, as might be supposed, prove that coal cannot heat with occluded oxygen alone. When he cut off the air supply the coal certainly cooled, but it was then over 100° C. and any occluded oxygen would have already combined with the coal below that temperature. Coal may heat with occluded oxygen, but as it gets hot fresh air must be supplied or it will cool again; such hot coal will, however, tend to draw in the fresh air required by means of convection currents.

<sup>1</sup> "The Weathering of Coal," Bulletin 17 of the University of Illinois Engineering Experiment Station.

If iron pyrites and the oxygen compounds of coal can react, it suggests that possibly also fresh coal and weathered coal may react and thus make a dangerous mixture. There is no clear evidence on this point; Fayol says that coal spread in successive layers of not more than 3 feet and with a lapse of time after each layer before putting down the next, forms a safe pile. Other writers say that coal once heated and cooled never heats again, and yet, the foreman of a coal yard in Montreal states that mixtures of old, heated and cooled, coal with fresh coal are very dangerous; and a case has been cited where in building a coal pile banking was stopped for a month and then continued, fires afterwards broke out all along the line of contact of the old and the new coal. These fires might be explained as being due to mixing, or possibly, the surface of the old coal was strongly heated by the sun when the new coal was put on the top. Coals from certain seams are said to keep cool when stored alone but to heat when stored together.

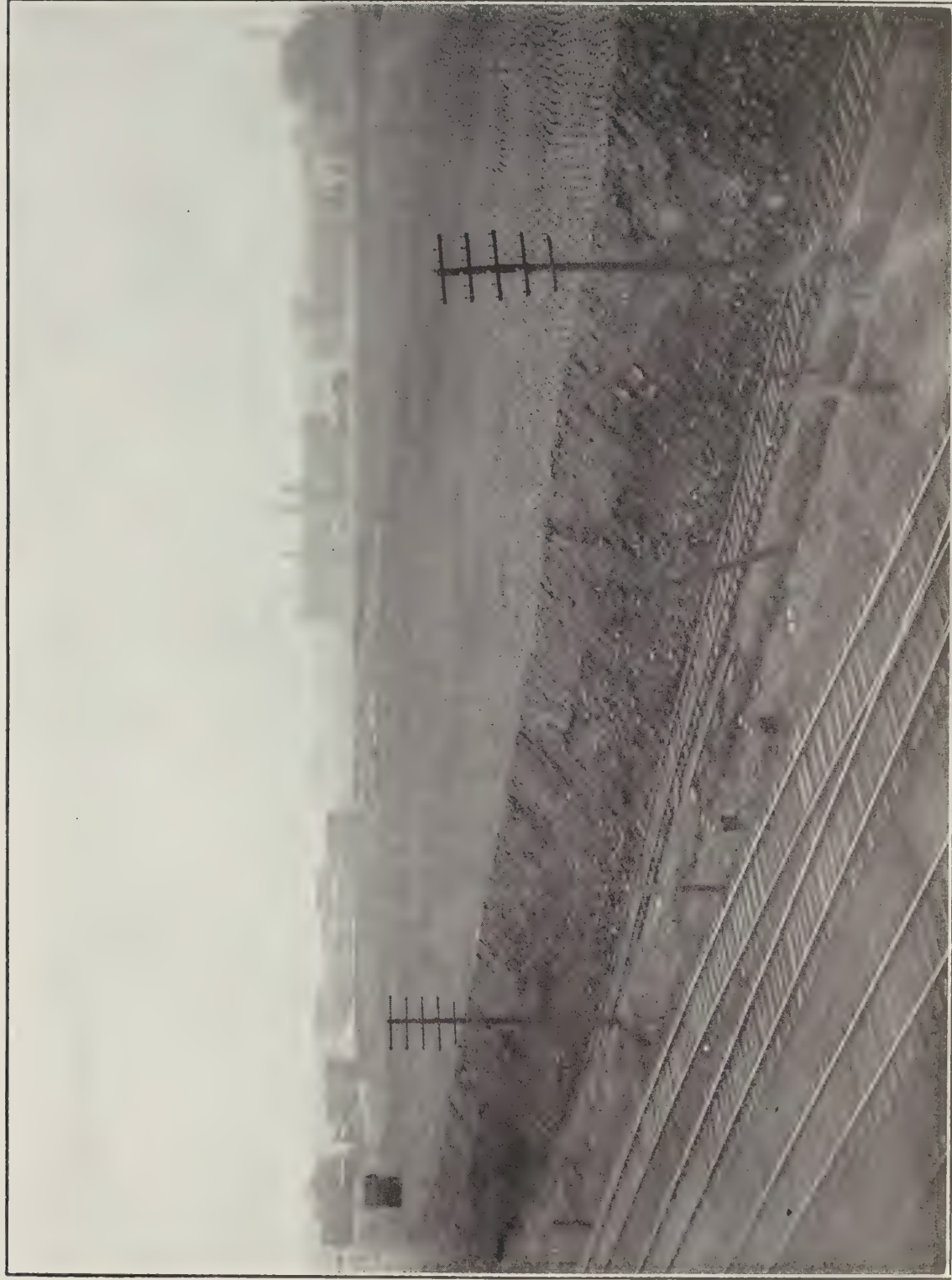
Coal is banked near the mines in Cape Breton in piles of 20 or even 30 feet high without a sign of heating, the same coal stored in Montreal heats in less than three months in piles of only half the height. This is probably because the coal in Cape Breton is in comparatively large lumps, comes straight from the mine saturated with hydrocarbons, and is stored in winter and, therefore, cold; whereas the coal in Montreal is more broken up and almost like slack, is saturated with air rather than with hydrocarbons, and is stored in summer and, therefore, often hot.

Remedies for trouble with coal piles are easy to suggest, but are often difficult and expensive to carry out. Storage under water has been successfully tried by the British Admiralty and others, and the former has also shown that coal briquettes can be stored without serious loss even in hot climates. Continuous storage under water could not easily be adopted in Canada, as in winter when the coal was wanted the water would be frozen; but it would probably be practicable to so store in a cement tank from which the water was drained in the autumn when it was reasonably cold.

Very few coals will heat if stored in piles of less than 10 feet high and a thicker pile can be safely made if it is very thoroughly ventilated. Fayol's suggestion of building up a pile in thin layers might be tried, or Threlfall's recommendation of spraying. Where fine coal can be used, as for example where coal dust firing is employed, the coal can be screened as received, the screenings used for immediate consumption and only the lump coal stored; as has already been stated piles of lump coal rarely, if ever, catch fire.

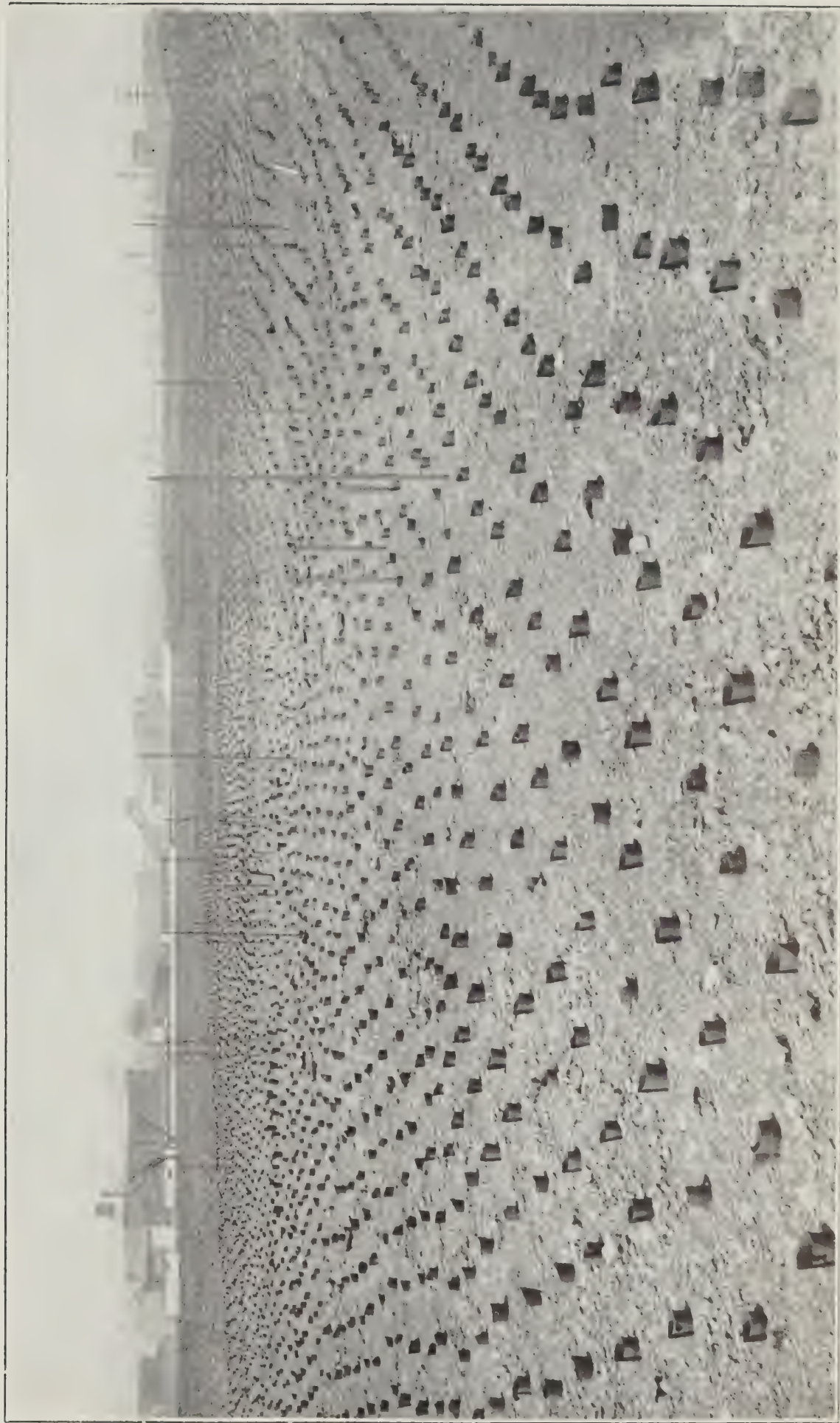
Plate I shows a general view of a ventilated coal pile of the Canadian Pacific Railway Co. near their Angus shops at Montreal; and Plate II is a nearer view of the same pile showing the openings of the ventilation holes, which holes pass from top to bottom of the pile. Plate III shows an unventilated coal pile on fire in Montreal.

PLATE I.



Ventilated coal pile at Montreal. General view.





Ventilated coal pile at Montreal.



PLATE III.



Unventilated coal pile on fire in Montreal.



The question is largely one of dollars and cents. A cement tank involves a large capital outlay; but with proper handling machinery the coal need hardly cost as much each year for storing as it would in an ordinary stock pile. A ventilated pile requires no capital beyond the handling arrangements also required for the unventilated pile; but the annual outlay in providing vent holes is considerable. Coal stored under water suffers no appreciable deterioration chemically or physically. Stored in air but kept fairly cool it may lose 5 per cent in value—authorities differ very much on this point; coal which heats although it does not actually fire, may lose up to 20 or 25 per cent of its value, and an actual fire may involve great expense to extinguish it, in addition to the damage to the coal. In any particular case the outlays involved and the economies effected must be considered in deciding between the different methods of storing. It is, however, greatly to be deplored that the coal resources of the country should be needlessly wasted by spontaneous combustion.

After this paper was written but before it was first printed in the *Journal of the Canadian Mining Institute*, an account of further work of the University of Illinois Engineering Experiment Station was published—Bulletin No. 38, "The Weathering of Coal, Series of 1909," by S. W. Parr and W. F. Wheeler. The conclusions from their experimental work are as follows:—

"Coal of the type found in Illinois and neighbouring States is not affected seriously during storage when only the changes in weight and losses in heating power are considered. The changes in weight may be either gains or losses of probably never over two per cent in a period of one year. The heating value decreases most rapidly during the first week after mining and continues to decrease more and more slowly for an indefinite time. In the coals that have been tested, one per cent is about the average loss for the first week and three to three and one-half per cent would cover the losses for a year, although in some instances the loss was found to be as high as five per cent in a year.

"The losses due to disintegration of the coal and to spontaneous ignition seem to be of far greater importance than any changes in weight and heating value although they cannot be expressed in figures for comparison. The storage of coal of a size larger than is to be used would overcome part of this objection to storage, as the coal would be crushed to the most advantageous size just before firing, the larger sizes of coal are also much less liable to take fire spontaneously. Storage under water will prevent disintegration of the coal to a very large extent, and it will absolutely prevent any fire losses. Aside from these advantages in favour of storing coal under water, there seems to be very little to be said in favour of any particular method of storing coal."

A coal pile should always be regularly tested until the probable period of incubation is past or until the temperature having first risen begins to steadily fall again. The simplest method of testing is by means of iron

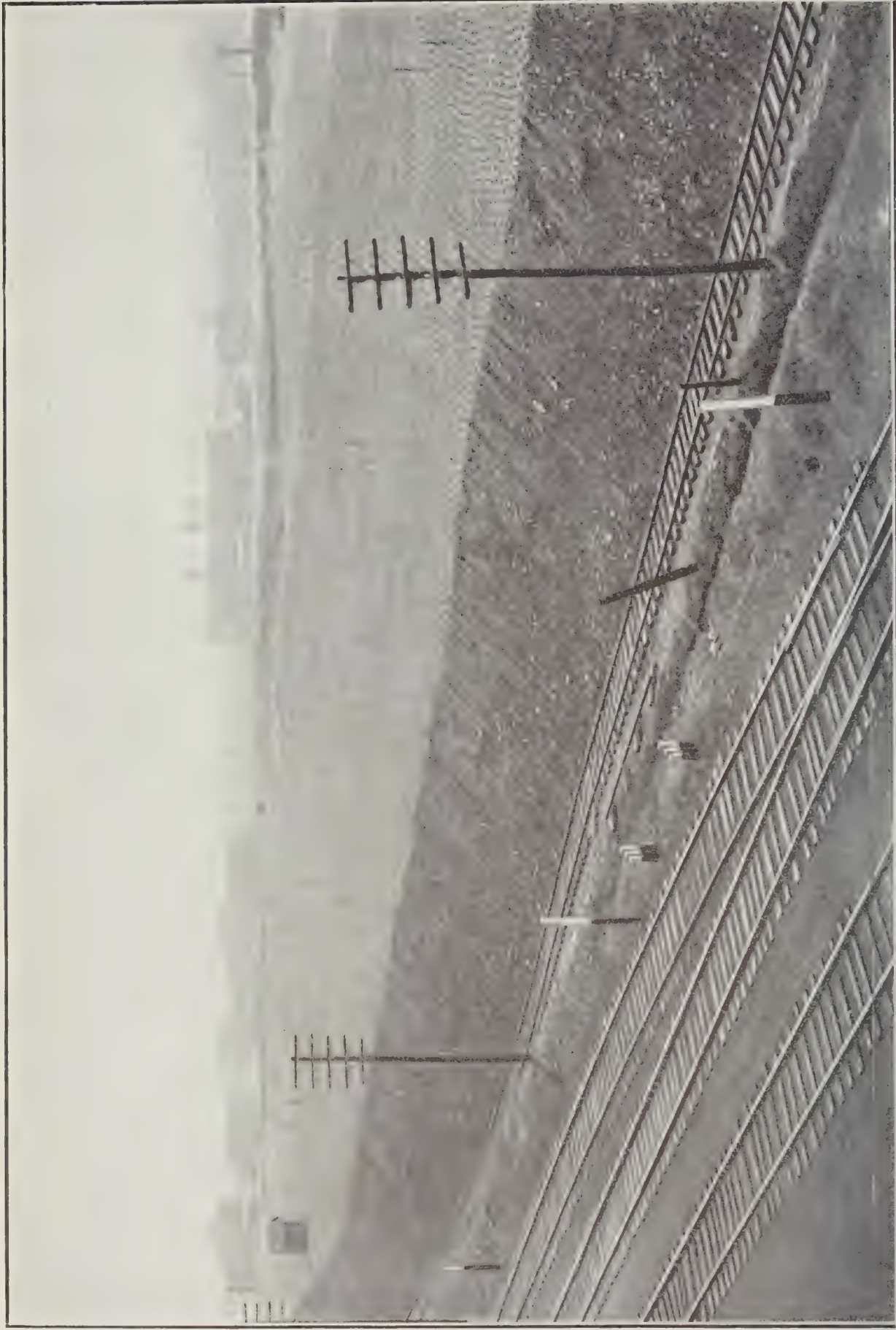
rods run down through the pile at frequent intervals; these can be seen in Plate II. They should be pulled out once or twice a week, their temperature being felt along their length, and then put back in a fresh place. If dangerous heat develops in a ventilated pile it is best treated by making extra ventilation holes; if this does not succeed, or in the case of an unventilated pile, it is well to dig away the hot coal and spread it out to cool. Digging out is also the best remedy in case of fire. It is well to begin by digging all round the heated spot to isolate it, as otherwise it may spread back into the rest of the pile as air gets to it.

Water is not found to be successful in extinguishing fires. In the first place the coal above the fire cokes and thus armours the fire over and the water cannot readily penetrate through. Cases have been known where in digging out ships' cargoes, hollow spaces were found near the bottom containing only ashes; a fire had begun, armoured itself over and burned out without its presence having been suspected. Secondly, water may cause the fire to spread, as the steam generated passing through the pile heats up fresh coal which also soon fires. Fayol showed that coal, even in small piles, soon fired if first heated to  $100^{\circ}$  C.

The subject of spontaneous combustion is a very large one and this paper comes far short of covering even the work already done; but it will at anyrate serve to indicate the incompleteness of our present information.

In conclusion, the writer wishes to thank Dr. Porter for his great assistance in obtaining references and papers, and for the photographs, and to thank him and others for their valuable information, criticisms, and suggestions.





General view of storage pile at Angus.

(Porter and Brunton)

Canada. Mines, Branch

**CANADA**

**DEPARTMENT OF MINES**

HON. LOUIS CODERRE, MINISTER; R. G. McCONNELL, DEPUTY MINISTER.

**MINES BRANCH**

EUGENE HAANEL, PH.D., DIRECTOR.

AN

**INVESTIGATION**

OF THE

**COALS OF CANADA**

WITH REFERENCE TO THEIR ECONOMIC QUALITIES:

AS CONDUCTED AT MCGILL UNIVERSITY, MONTREAL,  
UNDER THE AUTHORITY OF THE DOMINION  
GOVERNMENT.

EXTRA VOLUME  
SUPPLEMENTING REPORT No. 83

EX 10672

**WEATHERING OF COAL**

BY

**J. B. Porter, E.M., Ph.D., D.Sc.,**

ASSISTED BY

Stopford Lauder Brunton, A.M., M.Sc.; Joseph B. de Hart, M.Sc.;  
Edward Eric Billington, M.Sc.; Alan E. Cameron, M.Sc.;  
and Edgar Stansfield, M.Sc.



OTTAWA

GOVERNMENT PRINTING BUREAU  
1915

No. 338



LETTER OF TRANSMITTAL.

Eugene Haanel, Ph.D.,  
Director Mines Branch,  
Department of Mines,  
Canada.

Sir,—

I beg to hand you, herewith, a report on the Weathering of Coal, supplementing my report of November 7, 1910, on the Coals of Canada.

I have the honour to be, Sir,

Your obedient servant,

(*Signed*) **John Bonsall Porter.**

McGill University,  
December 28, 1914.



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## PREFACE.

In the autumn of 1906 the Canadian Government through its Department of Mines—then the “Geological Survey of Canada”—undertook an extended study of the fuels of the Dominion; but inasmuch as the Government did not at that time possess suitable fuel testing laboratories, and a considerable amount of research work had already been done by the Mining Department of McGill University, the author was invited to undertake the larger investigation.

The main results of the above mentioned work have been published by the Mines Branch of the Department of Mines, under the title of “The Coals of Canada, An Economic Investigation—6 vols., Ottawa, 1912-13.” This report presents, in great detail, a statement of the coal and lignite resources of the Dominion; a description of each of the important mines operating at the time; and the results of an extended series of experimental tests, on a semi-commercial scale, in coal washing, coking, steam-raising, and power gas producing. Each of these sections was prepared by a competent specialist, and contains a general discussion of its subject; a technical description of the tests made; a summary statement of the results of these tests; and an appendix giving full details of each experiment. The report, as a whole, then closes with a section devoted to the chemical methods employed, and their results.

In the above mentioned report attention was drawn to the fact that many coals oxidize rapidly in storage, and are liable to serious deterioration, or even destruction. Circumstances did not permit of an extended study of oxidation as a part of the original investigation; but the matter is especially important in Canada where climatic conditions necessitate the storage of large amounts of bituminous coal at central distribution points; and since the completion of the main report, the author and certain members of his staff have carried on a series of laboratory studies of the oxidation of coal at low temperatures. They have, moreover, made a study of the practical problem of coal storage, both at the mines and in Montreal, and also in other cities. These investigations have been by no means exhaustive, and no very novel conclusions have been drawn from them; but their results seem worthy of publication as a contribution to the literature of an important and difficult subject.

In addition to presenting reports on his own work, as above, the author has attempted in the present volume to bring together and summarize the more important writings of other investigators, and to present a somewhat extended discussion of the whole subject of the weathering of coal. He recognizes to the full the difficulty of his task and the impossibility of dealing adequately with it; but he hopes that his work will be of value to future students and investigators.

The literature of the subject is voluminous, but scattered, and often fragmentary and conflicting, and some of the most important contributions are in French or German or are in rare books and periodicals. The present work, which has been written in the spare hours of a busy life, makes no pretension to being a complete review of this literature; but it is believed that nearly everything of importance has been included, and, in the case of inaccessible or very important articles, full abstracts, or even extended quotations have been made, without hesitation.

In closing, the author wishes to acknowledge the valuable and most loyal aid of his several research assistants, whose names appear with his own on the title page. He also wishes to express his indebtedness to, and admiration for, the work of numerous investigators in the same field. It is impossible to name them all without repeating the bibliography; but especial reference must be made to the work of Dr. J. S. Haldane, F. R. S. of Oxford University, England; Professor W. S. Parr of the Engineering Experiment Station of the University of Illinois; and Dr. H. C. Porter of the United States Bureau of Mines, and to the research chemists working under their guidance.

McGill University,

December 18, 1914.

THE  
COALS OF CANADA:  
AN ECONOMIC INVESTIGATION.

---

WEATHERING OF COAL.

BY

J. B. Porter, E.M., Ph.D., D.Sc.

AND OTHERS.



## CHAPTER I.

# WEATHERING OF COAL.

## INTRODUCTORY.

### GENERAL DISCUSSION.

Coal has been in use in Europe for nearly eight hundred years, and has actually been shipped by sea from Newcastle to London and to France ever since the time of Henry III (1257). For centuries it has been known that some coals are liable to heat spontaneously and even take fire under certain conditions both in mines and in storage, but until comparatively recent years these facts have only been of practical importance in connexion with the mines, where spontaneous fires have been counted among the troubles to be faced ever since collieries of considerable size have been operated. The second case, that is to say, heating in storage, did not of course become a matter of practical importance until the development of steamships, railways and steam driven manufactories just before the middle of the last century rendered it necessary to establish coaling stations at all important ports, and to carry considerable reserves of coal at all railway and industrial centres. The first public interest in the matter was in connexion with the sending out of coal in cargo lots by sailing ships to naval stations. Such cargoes often caught fire, particularly in the case of long voyages through the tropics, and in due course the number of colliers posted as "missing" attracted so much attention that a Royal Commission on Coal Cargoes was appointed in England in 1876. Since then similar commissions have been created in other countries, and the subject has also been studied by a very large number of learned societies and private individuals.

In still more recent years another aspect of the difficulty has become important. The industrial use of coal and the public dependance upon it has increased and extended immensely, and with this has come the necessity of storing great quantities of fuel as a precaution against strikes of miners or transport workers, which might otherwise result in industrial paralysis and acute public distress. Every manufacturing establishment must now carry a considerable emergency supply of coal, and in the case of public service corporations such as railways, steamship lines, gas works, etc., the supplies now stored are often sufficient to last many months.

In Canada the problem is particularly serious, for in addition to the conditions above stated there is another important economic reason for storing very large quantities of fuel. The coal fields are, generally speaking, in the extreme east and almost the extreme west of the country, and

the main industrial population lies between them at a great distance from either. Industrial Canada may be said roughly to extend from Quebec to Sault Ste. Marie with its chief centres at Montreal and Toronto. These cities are 1,000 and 1,350 miles respectively from Sydney, Nova Scotia, which is the chief source of coal in eastern Canada, while Toronto is but 400 miles approximately from the centres of the anthracite and eastern bituminous coal fields of the United States.

From May until November, Nova Scotia coal can be sent to Montreal in large sea-going ships at rates of transportation averaging approximately one-third of those charged for rail shipments; and from Montreal, by a single transfer to smaller vessels, water transport becomes practicable not merely to Toronto, but as far west as Fort William.<sup>1</sup> Similarly, although to a less extent, American anthracite coal reaches Montreal by barge at rates which compare favourably with rail rates, and tend to control the latter during the season of navigation.

For five months each year water transport is impossible and all fuel brought in has to pay the relatively high rates of winter traffic by rail. These rates from Sydney to Montreal for example are approximately two dollars per ton higher than rates by sea. The difference in favour of water traffic is sufficient to more than pay the cost both direct and indirect of shipping the great bulk of each year's supply in advance by sea and storing it until needed. The total amount so stored is immense; Montreal for instance being estimated to have had one million tons of bituminous coal and a very large amount of anthracite in store at the end of the season of navigation in November, 1913, while other cities and railway centres all similarly had great stores of fuel.

Canadian coals unfortunately do not differ from other coals of the same class in their liability to weathering, and while few if any of our coals are as troublesome as certain notorious coals in other lands, yet several of the best known and most valuable steam coals in eastern Canada are liable to spontaneous combustion, and large sums of money are spent each year in Montreal and other cities in guarding coal storage piles against fires, and still larger sums in fighting the fires which do occur, and making good the damage which results from the fires themselves, and that resulting from heating which does not quite reach the ignition point.

In view of the facts above set forth, it has seemed proper that a volume on the Weathering of Coal should be included in the general economic study of the Coals of Canada which was undertaken by the Department of Mines some few years ago, and entrusted, through the Director of Mines, to the senior author of the present work.

As already stated, the subject of spontaneous combustion has engaged the attention of several Royal Commissions, and there have been a very

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<sup>1</sup> Very little sea-borne coal is actually shipped to Toronto and still less to Fort William, etc., because under the present tariff Pennsylvania and Ohio coals can be sold in most parts of Ontario at more favourable prices than Nova Scotian fuel. These American coals are, however, themselves transported by water to a considerable extent, and the fact that water transport is possible for several months in the year has a very potent influence in keeping down rail freights to all competitive points.

large number of official and private investigations. During the last three or four years in particular an exceptionally large number of persons have been at work and scores of papers have been written; but the problem is one of extreme complexity and the great majority of the investigations which have thus far been carried out may be looked on as attempts to study specific aspects of the case rather than to deal with the matter as a whole.

The most important of the early investigations of the behaviour of coal in storage were carried out by Fayol<sup>1</sup> at Commentry in France. His report which appeared in 1878 is full of valuable information, but its most salient feature is the conclusive proof that when a pile of Commentry coal under ordinary conditions has attained a certain temperature (about 100°C.) autogenous<sup>2</sup> or self-propelled oxidation begins. The influences which tend to raise the temperature of coal to this point have engaged the attention of all investigators of spontaneous combustion since Fayol's time.

The senior author of the present volume has been interested for several years in the particular problem of the safe storage of Nova Scotian coal, and to this end has conducted a number of practical experiments both in Montreal and at the mines. He has, fortunately, also been able to assign the subject for four years in succession to one or another of his departmental research assistants, and thus to carry out a considerable amount of exact laboratory work on certain features of coal oxidation. All of this original work is, however, but a fraction of what will have to be done before the problem can be considered finally solved.

This experimental work must, therefore, be looked on merely as a contribution to the general investigation that is being carried on throughout the world, and under ordinary circumstances the account of it should have been published as a paper in the transactions of some suitable technical society. So much public interest has, however, been aroused of late in spontaneous combustion that it has seemed desirable both to the Director of Mines and the author to attempt to present in a single volume a general statement of what is now known on the subject, and a considerable part of the present work is, therefore, a review of the most important papers that have been published on coal weathering.

The author has tried to present this matter in logical sequence, and to state the views of the several writers as fairly as possible, although he has not refrained from comment or criticism where either seemed desirable. He recognizes, however, that his essay is by no means above criticism itself; the literature of the subject is very voluminous, and on the whole very unsatisfactory, and all that can be claimed for the present volume is that it is

<sup>1</sup> *Études sur l'Altération, etc., de la houille exposée à l'air.* Paris, 1879.

This work has been reviewed and abstracted in English in the following publications:

Report New South Wales Royal Commission on ships carrying coal, 1897.

Review by Threlfall, *Jour. Soc. Chem. Ind.* Vol. 28, 1909, p. 763.

<sup>2</sup> This term autogenous oxidation is frequently misunderstood. All natural oxidation is in a sense autogenous, but for coal which has been stored, there is some particular temperature for each particular coal and each particular condition of piling, above which the rate of oxidation is so rapid that the heat of the mass is no longer kept down by natural radiation, etc., but rises more and more rapidly until actual ignition takes place. This matter will be considered at length in another part of this book.

a sincere attempt to summarize in a comparatively small number of pages, matter culled from some thousands of pages of reports, bulletins, transactions, etc., most of which are only to be found in the great public libraries.

The book deals also with the individual experimental work of the author and his associates. This work was highly special and concerns only a few points in a very complex matter, but the results are offered for what they are worth. The author believes that they have definite value as settling one or two questions and casting light on some others on which opinions have been at variance.

#### ORIGIN AND COMPOSITION OF COAL.

The generally accepted theory of the formation of coal is as follows:—

Vegetable matter of all kinds, but particularly the remains of ancient Equiseta such as Calamite, and Lycopods such as Lepidodendron and Sigillaria with their huge root-like stigmata, accumulated in thick layers and became massed together under conditions approximating those of swampy jungle of the present day. Eventually this vegetable matter was covered by the deposition of silt and mud, and this in turn by other stratified deposits often of great aggregate thickness. Through the agencies of heat and pressure in the earth's crust, the mass was next subjected to some sort of destructive distillation involving a gradual loss of water, oxygen and other constituents and resulting in the slow formation of coaly material, approximating more and more to pure carbon as time passed on. Anthracite is the last product which may be termed coal, further action of heat and pressure producing graphite. A coal which has arrived at the anthracite stage, will thus have passed through all the other stages during its formation: that is, first growing plants, then peat, lignite, bituminous coal and anthracite.

A great deal of light has been cast on the origin of coal by the study of thin sections under the microscope. By this means the original vegetable forms have been identified and studied, and the coaly material has been shown to consist very largely of accumulations of spores altered of course by heat and pressure, but still perfectly distinguishable.

Quite recently a very interesting contribution to this branch of the subject has been made by Lomax,<sup>1</sup> who has studied coals microscopically with especial reference to their liability to oxidation and spontaneous combustion. Still more recently a most valuable general work on the origin of coal has been published by the United States Bureau of Mines.<sup>2</sup>

As might be expected from its formation, the chief elements occurring in coal are also those which went to make up the plant body, although the proportions of course do not correspond, since the process of the formation

<sup>1</sup> (A). The Microscopical Examination of coal and its use in determining the inflammable constituents present therein. T. I. M. E. Vol. XLII, 1911, p. 2.

(B). Further researches in the microscopical examination of coal especially in relation to spontaneous combustion. T. I. M. E. Vol. XLVI, 1914, p. 592.

<sup>2</sup> The Origin of Coal—by David White and Reinhardt Thiessen—with a chapter on the formation of peat by C. A. Davis—Bull. 38, U. S. Bur. of Mines, 1913, pp. 1-304 and 54 photographic plates.

of coal tends to the loss of oxygen and hydrogen more rapidly than the other constituents and therefore, to the relative increase in the proportion of carbon. The common elements in coal are: carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, iron, calcium, magnesium, etc., the last four or five usually occurring in small proportions.

These elements are not merely linked up to form a few specific compounds. Many of the complex compounds, which existed in the plants from which the coal was derived, would each form whole series of degradation products during the slow transformation into coal. In every specimen of coal we get many compounds representative of some of the exceedingly numerous possibilities in the above series. There is no *prima facie* reason why any two different samples of coal should be alike in composition; for not only may different plants have gone to form their substance, but also the metamorphosis may have followed different lines. It can thus be easily understood that although a great amount of work has been done on the subject, very little is yet known of many of the actual chemical compounds existing in coal.

When coals are consumed, whether that destruction be in the form of slow decomposition such as weathering, or more rapid decomposition as spontaneous combustion, or actual burning in the furnace, the action is primarily the oxidation of the combustible matter of the coal, that is to say (a) the coaly matter itself and (b) the pyrite, marcasite and other sulphur compounds which the coal contains. Other heat-giving reactions may occur to a small extent in some cases, but in a practical sense the only combustible elements are carbon C, hydrogen H, and sulphur S. Of these elements the carbon greatly predominates in heating value although its heat is largely augmented by that from the hydrogen, or in other words, the coaly matter proper provides enormously the greater part of the total heat, but as will be shown later the pyrite and other sulphur compounds are supposed by some observers to be the first to oxidize, and therefore to play a most important part in the early stages of combustion.

Harger<sup>1</sup> says in an address to the Liverpool section of the Society of Chemical Industry, that coals are conglomerates of four classes of bodies:

#### Approx. Composition and Calorific Value.

	Carbon	Hydrogen	Oxygen	Cal. Val.
	%	%	%	
1. Carbon residuum	96	2½	1½	8,765
2. Resins	79	10	11	9,130
3. Humus bodies	63	5	32	6,480
4. Hydrocarbons	75-85	25-15	0	12,000

<sup>1</sup> Society of Chemical Industry. Vol. XXXI, February 1912, pp. 413-416.

1. *Carbon residues* contain little volatile matter; occur largely in anthracites and hard steam coals, and in bituminous coals to a lesser amount.
2. *Resin bodies* contain very little hygroscopic moisture, melt and decompose between 300°C and 400°C; and below 500°C they yield soft coke; heated above 500°C they decompose rapidly, yielding hydrogen, hydrocarbon gases and hard coke.

These resin bodies and their derivatives, the humus bodies, are believed by many authorities to play a major part in the spontaneous combustion of coal. This matter will, however, only be touched upon here as it is dealt with at some length in another section.

There are two classes of these bodies (a) unsaponifiable by alkali, not oxidizable by warm air, and insoluble in pyridine; (b) soluble in pyridine, saponifiable by alkali, and oxidizable to humus bodies by warm air. These are the bodies upon which Parr worked, using phenol as a solvent. He says that they are oxygenated compounds which exist in coal and can be removed by phenol, and that they are unsaturated, and can take up oxygen. After distillation the distillates are equally active with respect to oxygen. They have definite melting points. The resin bodies are those whose presence decides the coking power of a coal; if too great a quantity is present the coke as it forms will swell and burst itself, just as sugar does when heated: if excessively resinous coals are to be coked they should, therefore, be mixed with some inert carbonaceous substance such as coke breeze.

The origin of these resin and humus bodies, and the part they play in spontaneous combustion is dealt with from the microscopical point of view by Lomax.<sup>1</sup>

Fayol classes coals which are liable to heat in the following natural order: Lignite, Bituminous, and Anthracite. It can be readily understood that bituminous coals containing large quantities of easily attacked resin bodies are the ones which generally heat most readily; peaty lignites, and some lignites themselves, also heat readily, but this fact is of theoretical interest only as they contain so much oxygen, water, etc., that they keep very badly, and having a very low calorific value there is little commercial reason for storing them. On the other hand coals approximating to anthracite resemble carbon more and more in their stability when exposed to air.

Dennstedt and Bünz<sup>2</sup> ascribe increase of absorption of moisture by coal to the humic acids which are gradually formed as oxidation of the resin bodies proceeds. They state that the last products of the reaction are mainly humic acids, and the quantity of these acids present is, therefore, an indication of the heating tendency of a coal.

<sup>1</sup> Same reference as (1A and B) on page 4.

<sup>2</sup> *Zeitschrift für ang. Chemie.* (1908). Vol. 35, pp. 1825-35.

The above mentioned resin bodies are presumably those to which Parr and Kressmann<sup>1</sup> refer when they speak of the avidity of freshly mined coals for oxygen, which gas enters into combination with the unsaturated hydrocarbons of the coal.

Fischer<sup>2</sup> made use of the oxidizability of these resins as an indication of the liability of a coal to heat. He heated a weighed sample with a definite quantity of an oxidizing agent like bromine water.

Stansfield<sup>3</sup> draws attention to the similarity between the production of acids by oxidation of aldehydes, and the production of acids (humic) by oxidation of coal.

3. *Humus bodies* are similar in chemical composition to woody fibre, they retain a considerable amount of water which is only removed at 105°C; they have a lower percentage of carbon than shown in the table (p. 5) as Harger's figures are calculated free of nitrogen, ash and water. Large quantities occur in peat and lignites, lesser quantities in cannels and bituminous coals, and none in true anthracite.

Boudouard<sup>4</sup> worked on these bodies, and shows that the chemical constituents of the humic substances obtained by extraction from coal by means of potassium hydroxide solution, correspond with one or more of the following formulæ:—

1.  $C_{18}H_{14}O_6$  (Berthelot and Andre)
2.  $C_{18}H_{14}O_9$  (Malaguti)
3.  $C_{18}H_{14}O_{11}$

and that the effect of oxidizing the coal is to diminish the percentage of carbon, and increase the hydrogen and oxygen content of the humic substances.

Treatment with potassium hydroxide, hydrochloric acid and Schweizer's reagent completely destroyed the coking power of a coal, probably because the cellulose-like substances were removed.

Boudouard also points out that the humic acids are probably the carbohydrates of the original coal in a condensed and polymerized condition, just as polyatomic alcohols, sugars, etc. furnish resins by treatment with alkalis, acids, or by heat.

Chemically similar humic substances, artificially prepared, resemble those extracted from peat and lignite, which adds credence to the theory of the formation of coal aforementioned.

4. *Hydrocarbons* chiefly methane, occur in large quantities in some coals, ethane and higher paraffins may also occur; but these constituents need not be further discussed here.

<sup>1</sup> University of Illinois Exp. Sta. Bull. 46 (1910).

<sup>2</sup> Die Brennstoffe Deutschlands, etc. Braunschweig, 1901, pp. 1-107.

<sup>3</sup> Jour. Can. Mining Inst. Vol. XIII, 1910, p. 196; and Coals of Canada, Vol. VI, 1912, pp. 95-120.

<sup>4</sup> Bull. de la Societe Chimique, Ser. 4, Vol. V, 1909, pp. 365, 372, 377, 380.

Compte Rend. 147, p. 986; 148 p. 284 and 348—1909.

## HISTORICAL SURVEY OF PREVIOUS INVESTIGATIONS ON WEATHERING OF COAL.

In the following six pages an attempt is made to summarize very briefly the statements of a number of the more important writers in chronological order. The literature of this subject is very voluminous, and only a fraction of the papers are mentioned. In subsequent pages several of the papers referred to and others not mentioned here will be extensively quoted or abstracted and their conclusions discussed. A much more complete bibliography will be found at page 184 et seq.

The earliest authoritative discussion of the causes of weathering and particularly of spontaneous combustion seems to have been in a series of three reports to the British Parliament by **De la Beche and Playfair**, (1846-50) on "Steam Coals for the Royal Navy". They discuss the probable causes of heating and give analyses and arguments leading to the conclusion that considerable quantities of fines or dust in the coals are more likely to give trouble than the mere presence of pyrite.

**Regnault**<sup>1</sup> (1855), experimented with coals which he analysed, sealed up in corked flasks and set aside for twenty years; on re-analysis he could detect no alteration, probably because his chemical methods were not sufficiently delicate. Regnault, no doubt following Berzelius, however, states that pyritic coals are known to weather.

**Marsilly**<sup>2</sup> in his "Etude des houilles consommées sur la marche de Paris," notes that he believes that coals from gassy mines suffer change on exposure to air, but he does not venture to express an opinion regarding non-gassy coals. Marsilly also notes that coal dust exposed to air loses hydrocarbons, and also some of the substances which determine coking power.

**Grundmann**<sup>3</sup> (1862) conducted extensive experiments on the weathering losses of coal, and found that large pieces weather less than small; he also found that increase of temperature accelerated the weathering. His experiments on the loss in weight of coal were chiefly of use in that they attracted attention to the subject, his high apparent losses being probably due to poor sampling.

**Percy**<sup>4</sup> (1864) was apparently the next observer to ascribe spontaneous combustion of coal chiefly to oxidation of the carbonaceous matter of finely divided coal (dust) rather than to the pyrite as had commonly been assumed.

**Varrentrapp**<sup>5</sup> (1865) kept coal at a constant temperature of 284° C, and claims that it was soon completely oxidized, the coal itself, however, must have risen to a much higher temperature.

<sup>1</sup> (A). Annales des Mines, 3rd Series t. XII, 1837, pp. 161-240.

(B). Rapport sur la fabrication des gaz—Annales des Mines, 5th Series t. VIII 1855, pp. 1-67.

<sup>2</sup> Etude des houilles consommées sur la marche de Paris, Annales des Mines, 5me Series t. XII, 1857, pp. 347-416

<sup>3</sup> Carnall's Zeitschrift. Vol. X, 1862, p. 236.

Kerperly Bericht, 1866, pp. 32, 33.

Zeitschr ft fur Berg Hütten. u. Salin, Vol. X, 1862, pp. 326-332. Vol. XIV, 1866, pp. 52-72.

<sup>4</sup> Chemical News, Vol. X, 1864, p. 19.

"Metallurgy". Vol. Fuel I, 1875, pp. 289-298.

<sup>5</sup> Dinglers Poly. Journal, Vol. 175, 1865, pp. 156-158.

Dinglers Poly. Journal. Vol. 178, 1865, pp. 379-384.

**Fleck**<sup>1</sup> (1865) analysed six coals which had weathered for some years, and noted a decrease in carbon and available hydrogen, accompanied by an increase in oxygen and non-disposable hydrogen.

**Thompson**<sup>2</sup> (1865) noted that in six months a dry coal lost 13% of its calorific value, but that if the coal was moist, the loss was much greater.

**Reder**<sup>3</sup> (1866) followed up Grundmann's work and using the same kind of coal found small increase of weight, but no practical changes. In a German coal he found a loss of calorific value of about 4%.

**Richters**<sup>4</sup> (1868) concluded that oxygen was absorbed by coal, part being again given off as carbon dioxide and water while the rest remained in combination. He found that the absorption was at first rapid, but later became very slow; he thought that the only effect of moisture is to disintegrate the coal when pyrite is present.

**Pechin**<sup>5</sup> (1872) stated that bituminous and semi-bituminous coals weather most severely, the former losing 10 to 25 per cent of its carbon upon exposure to the atmosphere, but he gives no figures to prove his statement, which is undoubtedly incorrect or rather very greatly exaggerated.

**Rothwell**<sup>6</sup> (1873) says from his experiments that no losses were noted in the cases of anthracite and bituminous coals, except when using small sizes of the latter.

**The English Royal Commission**<sup>7</sup> (1876) ascribed spontaneous combustion to pyrites, condensation of oxygen on the surface of the coal, and to oxidation of the coal matter itself.

**Haton**<sup>8</sup> (1878) says the cause of heating lies in the combustible itself, possibly aided by the presence of pyrites. He notes also that air must be present.

**Kimball**<sup>9</sup> (1879) discusses loss of coking power due to weathering, and thinks the weathering of marcasite and pyrite is of as much importance as the weathering of the coal itself.

**Fayol**<sup>10</sup> (1879) ascribes the main cause of heating to the coal itself.

Admixture of extraneous pyrites with the coal did not appear to hasten the spontaneous heating.

Adverse weather had no injurious effect upon the coal stored in piles, in so far as could be detected.

Coal piled to a depth of less than two metres did not suffer spontaneous combustion.

<sup>1</sup> Die Steinkohlen Deutschlands, 1865, Vol. II, p. 221.

<sup>2</sup> Abstr. Percy—Fuels, 1875, pp. 290-2.

<sup>3</sup> London Journal of Arts. June 1865, p. 321 (P. and K.)

<sup>4</sup> (A) Zeit. Verein deutsch. Ing. Vol. X, 1866, p. 698.

(B) Oest. Zeitschrift für Berg und Hutton., Vol. XV, 1867,

<sup>5</sup> Dinglers Poly. Jour. Vol. 190; 1868, p. 398.

<sup>6</sup> Dinglers Poly. Jour. Vol. 193; 1869, pp. 54 and 264.

<sup>7</sup> Dinglers Poly. Jour. Vol. 195; 1870, pp. 315 and 449.

<sup>8</sup> Trans. Am. Inst. Min. Eng. Vol. I, 1872, p. 285.

<sup>9</sup> Trans. Am. Inst. Min. Eng. Vol. II, 1873, pp. 144-152.

<sup>10</sup> English Royal Commission, "Spontaneous Combustion of Coal in Ships," 1876.

<sup>11</sup> Rapport de la Commission d'études des moyens propre à prévenir les explosions de gison; 1878.

<sup>12</sup> Trans. Am. Inst. Min. Eng. Vol. VIII, 1879, pp. 204-225.

<sup>13</sup> Études sur l'altération et la combustion spontanée de la houille exposée à l'air; 1879.

**Haedicke**<sup>1</sup> (1881) thought that pyrites is the primary cause of heating in coal.

**Lewes**<sup>2</sup> (1890) discussed the effects of the presence of inorganic matter in coal; he also discussed spontaneous heating in general, especially with regard to the occurrence of the same in ships. Lewes concluded that pyrites played a large part in spontaneous heating.

**Erdmann and Stolzenberg**<sup>3</sup> (1907) think that humic acid is the prime cause of heating, especially where ozone is present in the air as at sea. They record some very interesting experiments.

**New South Wales Commission**<sup>4</sup> (1897-8). In the evidence heard before the Commission the question of depth of storage piles was shown to be one of great importance. This had, of course, been conclusively shown by Fayol previously.

**Haldane and Meachem**<sup>5</sup> (1898) show from experiments that mine air is usually at a higher temperature than the seam and strata through which it circulates; they also sealed coal in flasks and obtained a reduction in pressure, the residual gas being nitrogen. Haldane and Meachem arrived at the following conclusions:—

“1. The rate of absorption of oxygen is proportional to the partial pressure of the oxygen present.

2. The rate of absorption of oxygen is doubled for every 30° C rise.

3. The rate of absorption of oxygen decreases as time goes on.

4. Absorption goes on at the coal surface and does not penetrate very deeply.”

**Hale and Williams**<sup>6</sup> (1899) found that a bituminous coal lost from one-half to one per cent of its calorific value in eleven months.

**Fischer**<sup>7</sup> (1901) concluded that weathering of coal is due to oxidation, that actual wetting hastens the weathering of pyrite and marcasite, and that many coals contain organic sulphur compounds. Fischer proposes as a test that a gramme of any finely powdered coal be shaken with 20 c.c. of half normal bromine solution for five minutes, and if any smell of bromine remains, the coal may be safely stored.

**Macaulay**<sup>8</sup> (1903) after conducting steaming tests with locomotives, concluded that English coal depreciates ten to twelve per cent per year in storage.

**Doane**<sup>9</sup> (1904) concluded that the amount of moisture left on air drying is an indication of liability of coal to heat when stored.

<sup>1</sup> Dingers Poly. Jour. Vol. 239; 1881, pp. 148-9.

<sup>2</sup> Trans. Inst. of Naval Arch. Vol. XXXI, 1890, pp. 204-228.

Jour. Soc. Arts. Vol. 40, 1892, pp. 352-365.

<sup>3</sup> Braunkohle Vol. VII, 1908, p. 69.

<sup>4</sup> New South Wales Royal Commission on Ships carrying Coal; 1897-8.

<sup>5</sup> Trans. Soc. Min. Eng. Vol. 16; 1898, p. 457.

<sup>6</sup> Trans. Am. Soc. of Mech. Eng. Vol. XX, 1899, pp. 333-341.

<sup>7</sup> Die Brennstoffe Deutschlands, etc., 1901, pp. 1-107.

<sup>8</sup> Practical Engineering. Vol. XXVIII, 1903, pp. 318-320.

Engineer (London), Vol. 96, 1903 p. 415.

<sup>9</sup> Engineering News, Vol. 52, 1904, p. 141.

**Durand**<sup>1</sup> (1883) thought spontaneous heating was induced in coal piles by the pyrites present first taking fire. This as already explained is an old opinion which is no longer held by the majority of observers. It is, however, no doubt true of some coals.

**Heideprin**<sup>2</sup> (1907) stored coal under water, and states that during seven months it lost from 0·8% to 8·5% of calorific value. The losses for coal in the air are reported as being very little more than this. These results are contrary to the observations of all other experimenters, and it is probable that something went wrong either with his sampling or his calorimetric work. Possibly however, the coal tested was abnormal.

A **German gas engineer** (1907) is quoted by Porter and Ovitz<sup>3</sup> as having claimed that he found a loss of 1·7% of calorific value per week for fine coal. This statement could only be true of a very exceptional coal; but it typifies a very prevalent and exaggerated opinion as to the rate of loss.

**Fessenden and Wharton**<sup>4</sup> (1908) claim that the percentage of volatile matter is an indication of the liability of a coal to heat. This statement is only to be taken in a very broad sense. It could not be trusted as between any two individual coals.

**Dennstedt and Bunz**<sup>5</sup> (1908) passed oxygen through coals at elevated temperatures. They found that coals which have been thoroughly wet, kindle more rapidly than those that have been kept dry; also they state that "self ignition increases in a ratio corresponding to the amount of moisture in air-dry coal." They further point out that coals which contain the most oxygen are most liable to heating, and describe several chemical methods of predetermining the liability of coal to spontaneous combustion.

**Parr and Hamilton**<sup>6</sup> and **Parr and Francis**<sup>6</sup> (1908) studied the weathering of coal and the changes which take place in coal when subjected to low temperature distillation. Their conclusions will be quoted later.

**Parr and Barker**<sup>7</sup> (1909) found that after mining, coal commenced to absorb oxygen at the same time evolving methane; and that after two months all the methane had passed away, but absorption of oxygen continued.

**Boudouard**<sup>8</sup> (1909) working from the chemical side of the question of loss of coking power, proved the formation of humic acids caused by oxidation of the coal matter and showed that the presence of these acids is very detrimental.

**Parr and Wheeler**<sup>9</sup> (1909) experimented on the weathering of bituminous coals from Illinois. Their report which covers a large amount of experimental work will be freely quoted in the body of the present work.

<sup>1</sup> Journ. Soc. of Chem. Industry, Vol. 2, 1883, p. 325.

<sup>2</sup> Power, Vol. 27, 1907, p. 437.

<sup>3</sup> Tech. Paper 16, U.S. Bureau of Mines, 1902, p. 4.

<sup>4</sup> Bull. Univ. of Missouri, Eng. Series, Vol. I, 1908.

<sup>5</sup> Zeitschrift für Ang. Chemie, Vol. 35, 1908, pp. 1825-35.

<sup>6</sup> Bull. No. 17 and 24, Univ. Ill. Exp. Sta., 1908.

<sup>7</sup> Bull. 32 Univ. of Illinois Exp. Sta., 1909.

<sup>8</sup> Bull. de la Société Chimique, Ser. 14, Vol. V, 1909, pp. 365, 372, 377, 380.

Compte Rendu, 147, 1908, p. 986; 148, 1909, pp. 284 and 348.

<sup>9</sup> Bull. 38, Univ. Illinois Exp. Sta. 1909.

**Porter, Ovitz**<sup>1</sup> and others (1910) have been engaged for some years on the study of the constitution and decomposition of coal. Their results, which have in the main appeared in publications of the U.S. Bureau of Mines, are of very great value and numerous quotations and abstracts from their work will be found in the following pages.

A distinction should be noted between H. C. Porter whose work is here referred to and J. B. Porter, the senior author of the present volume.

**Parr and Kressmann**<sup>2</sup> (1910) experimented on bituminous coals from Illinois to determine their rate of heating under various conditions. Their report, on the Spontaneous Combustion of Coal, is a very valuable work, and its conclusions will be referred to repeatedly in the following pages. They also supplement the description of their own tests with an extended review of the literature of the subject.

**Habermann**<sup>3</sup> experimented with coals at 50° C. in a fire-brick retort, and, supplying them with air at 26° C., ignition occurred in 36-39 hours. He found that the most easily oxidizable coals were those which were attacked by bromine with greatest avidity.

**Dennstedt and Schaper**<sup>4</sup> (1912) experimented with coals in a current of oxygen at a temperature of 150° C. They concluded that coals which show no tendency to increase in temperature under these conditions are absolutely safe; that coals which may heat locally, but do not heat generally in one hour are safe enough for transport in ships, and for storage in piles; that those which ignite within one hour are unsafe; and that those which ignite when subjected to the same tests at temperatures below 150° C. are exceedingly dangerous.

They also note that the greater the percentage of oxygen in the coal the greater will be the liability to give trouble.

**Lamplough and Hill**<sup>5</sup> (1913) after experimenting on several English coals, chiefly from the Barnsley seam, came to the conclusion that pyrite plays a larger part in spontaneous combustion than the majority of recent students have believed. Their paper and its discussion and criticism are of considerable interest and will be dealt with later.

**Winmill**<sup>6</sup> (1914) describes the first of a series of experiments which are now being carried on for the Doncaster Coal-owners Association. He discusses the relative rates of oxidation of various parts of the Barnsley seam, the effect of size of the coal dust particles on the rate of oxidation, the effect

<sup>1</sup> (a) Losses in storage of coal (H. C. Porter) Journ. Ind. and Eng. Chem. Vol. II, 1910, pp. 77-83.

(b) The volatile matter of coal (Porter and Ovitz) Bull. No. 1. U. S. Bureau of Mines, 1910.

(c) The escape of gas from coal (Porter and Ovitz) Technical Paper No. 2, U. S. Bureau of Mines, 1911.

(d) Deterioration and spontaneous heating of coal in storage. Tech. Paper No. 16, U. S. Bur. of Mines, 1912.

(e) The Spontaneous Combustion of Coal, 8th International Congress of Appl. Chem. Vol. X, 1912, pp. 251-267.

(f) The weathering of the Pittsburgh coal bed (Porter and Fieldner) Tech. Paper No. 35 U. S. Bur. of Mines, 1914.

(g) A study of the oxidation of coal (Porter and Ralston) Tech. Paper 65, U. S. Bur. of Mines, 1914.

<sup>2</sup> Bull. 46 Univ. of Illinois Exp. Sta. 1910.

<sup>3</sup> Schillings Jour. für Gasbel. Vol. XLIX, 1906, pp. 419-422.

<sup>4</sup> Zeit f. Ang. Chemie Vol. 51., 1912. pp. 2625-2629.

<sup>5</sup> "The Slow Combustion of Coal Dust and its Thermal Value." T. I. M. E. Vol. XLV, 1913, pp. 629-657

<sup>6</sup> "The Absorption of Oxygen by Coal." T. I. M. E. Vol. XLVI, 1913, pp. 559-591.

of temperature on the rate of oxidation and the effect on the rate of oxidation of variations in the oxygen content of the air current.

**Lomax**<sup>1</sup> (1911 and 1914) whose work has already been referred to on page 4 studied coals under the microscope with reference to their composition and liability to spontaneous heating. He finds that coals which are particularly troublesome almost always contain dull-looking bands of amorphous material, and he believes that fires usually start in this material which is particularly pulverous. He suggests that these bands may be the result of forest fires at the time that the coaly matter was being laid down. He also discusses the effect of pyrite which he does not consider a primary cause of combustion in most cases. His papers are very interesting and suggestive.

**Morris**<sup>2</sup> (1914) discusses the experience of Lydbrook Colliery in the Forest of Dean with reference to underground fires. The seam is particularly liable to spontaneous combustion, and the method of mining had to be modified with a view to meeting this difficulty. Ordinarily the coal or gob took fire about seven weeks after its first exposure, but the length of time depended upon the degree of pressure and also of course upon the amount of very fine material. When the compression was very great so little air entered that little or no heating occurred, but if, even after some months of these conditions, the pressure was reduced or a new way opened up for the admission of air, heating immediately took place. He also notes that material which has once started to heat and has been checked is particularly liable to heat again.

#### SUMMARY OF CONCLUSIONS.

From the results as set forth by all investigators dealing with the subject of weathering, the main causes seem to be the following:—

(1) The presence in the coal of complex and more or less unstable carbonaceous compounds such as resins, humus, etc., which oxidize readily.

(2) The presence of pyrite and marcasite in the coal, these minerals being effective both as disintegrating agents and also as actual sources of heat.

(3) The presence of moisture, which, whether or not it aids in the oxidation of the coal itself, certainly hastens the decomposition of pyrite which is always present to some extent.

(4) The physical condition of the coal itself is of vast importance as oxidation is largely superficial, and fine coal, and particularly coal dust, presents an immense surface to the air as compared with an equal quantity of lumps.

<sup>1</sup> (a) "The Microscopical Examination of Coal and its use in determining the inflammable constituents present therein." T. I. M. E. Vol. XLII, 1911, p. 2.

(b) "Further researches in the microscopical examination of coal, especially in relation to spontaneous combustion." T. I. M. E. Vol. XLVI, 1914, p. 592.

<sup>2</sup> "Notes on gob fires, etc." T. I. M. E. Vol. XLVII, 1914, p. 195.

(5) The presence of air as the source of oxygen is of course essential to oxidation, but a great excess of air, while facilitating oxidation of certain constituents, will also carry off the heat generated, and thus keep the coal cool and in this way prevent the coal from reaching the high temperature necessary for very rapid oxidation. It is thus possible to prevent oxidation altogether by absolutely excluding air, or to prevent undue heating by ensuring thorough ventilation. When, however, a limited, but sufficient, supply of air reaches the coal the destructive action is most rapid. In this connexion also, the physical condition of the coal is important, as dust, while it retards the passage of air, does not by any means prevent it.

(6) The way in which the coal is stored is of great importance in connexion with the last named points. A low thin pile ordinarily receives enough air to keep it cool; a high pile by its own weight compresses its lower portion and reduces the voids. There is thus a level or zone in any very high pile in which the conditions for heating are at a maximum while the deeper parts of the pile may get too little air and the portions near the surface too much for dangerous heating.

(7) The individuality of the coal is a factor of prime importance, for although certain types such as resinous lignite and bituminous coal are of course most easily oxidized, and other types such as anthracite and semi-bituminous are very slightly affected, yet chemical analyses and physical appearances alone do not always suffice to enable us to determine the relative susceptibility to weathering, and of any two coals which are apparently alike in composition and condition, one may prove to weather very much more rapidly than the other.

## CHAPTER II.

## A GENERAL DISCUSSION OF WEATHERING.

## WEATHERING IN NATURE.

Weathering in nature takes place at and near the outcrop of coal seams, and in some cases this action has even resulted in spontaneous combustion, and considerable quantities of coal have been completely or partially destroyed in place in the beds.<sup>1</sup> Ordinarily, however, the natural weathering of seams is too slow to cause fire, and all that happens is the disintegration of the coal, accompanied by the loss of part of its combustible matter, and a more than equivalent increase in ash. Outcrop coals are thus almost always of poor quality, but fortunately the damage rarely penetrates far into the seam, and coal as ordinarily mined shows little or no sign of oxidation in the destructive sense in which the term is used in this discussion.

The artificial or commercial weathering of coal begins the moment the miner's pick exposes its surface to the air of the mine, and this weathering continues with increasing, or decreasing intensity, depending on circumstances as long as the coal is exposed to the air. Weathering may thus be considered as taking place (a) in or near outcrops or fissures in nature; (b) in the coal mines; (c) on the surface during preparation and in transit; (d) in storage while awaiting use.

The first case is of little interest or importance except to the geologist and will not be discussed in this report, but the other cases are all deserving of separate consideration, although the general phenomena of weathering are alike in all.

## WEATHERING ACTION TAKING PLACE IN THE MINE.

Changes undoubtedly commence to take place in coal immediately upon mining, owing to the alteration of conditions. Coal in situ is under pressure due to the superincumbent strata, and it is also absolutely removed from contact with the atmosphere, but as the mining operations approach the coal the gases, which it ordinarily contains under pressure, begin to escape. This evolution of gas becomes more rapid when the coal is actually broken down, and for a time probably almost protects it from oxidation, but both oxidation and desiccation no doubt commence almost immediately and increase as the escaping gases decrease, and cease to protect the coal from the action of the air.

<sup>1</sup> The Burning of Coal Beds in place, by A. Bowie, Am. Inst. Min. Eng. Bull. 86, pp. 195-204, February (1914).

### Evolution of Gas.

Parr and Wheeler have shown that a combustible gas is given off by coal immediately upon mining; they sealed coal up in air-tight jars, and found that after ten months the vessels were filled with a combustible gas under pressure.

Taffanel states that it is during the first ten days after mining that the greater part of the available methane is set free; he obtained a liberation of 14—22 c.c. per grm. of coal. These figures do not include the methane evolved during the period elapsing immediately after breakage at the face.

Porter and Ovitz believe that methane is formed by slow decomposition of the coal, and they quote the work of Chamberlin, in which he crushed coal under a high vacuum, obtaining only a quantity of gas equal to one-fourth the volume obtained by bottling for six months. During two weeks after mining they found that a certain coal lost three-fourths of its own volume of gas, and after five months it has lost an amount equal to one and three-fourth times its own volume. They seem to think that this is a great deal, and in a chemical sense it may be, but from the practical standpoint it is of little importance except in the case of coal carriage in ships. If we consider the huge volume of air which sweeps constantly through a mine and the amount of gas given off by the coal during development work and before it is mined, this gas from the mined coal is unimportant: although, of course, immediately bad ventilation comes in, we have an entirely different situation. The loss in calorific value due to the escape of this  $1\frac{3}{4}$  volumes of methane if calculated out, is seen to be negligible as compared with other weathering losses.

Taffanel draws attention in his paper to the evolution of methane from coal in the mine, he, however, attacks the subject chiefly from the point of dust explosions; he gives figures for the quantities of gas given off by the samples upon which he experimented.

In this, as in every other action which we are to study in connexion with this subject, every coal has its own individuality, due in part to the particular condition of pressure, water, associated strata, etc., in the mine; and in part to the exceedingly complicated organic compounds, resins, albuminoids, etc., of which it is composed.

### Absorption of Oxygen and Oxidation.

This subject will be taken up at length in subsequent pages, but we may perhaps here quote certain observers who have particularly studied underground conditions. Porter and Ovitz following various earlier writers, state that "the air in a poorly ventilated section or closed portion of a mine is deficient in oxygen, and contains much less carbon dioxide than it would if all the oxygen that must have been removed from the air by the coal were immediately split off in combination with carbon." This absorption of oxygen is due in part to the coal left in the walls and pillars,

but in most cases the chief absorption is by the broken coal and carbonaceous shale, and particularly by the coal and shale dust which is always produced in mining.

Parr and Wheeler state that pillar coal in a particular district after 25 years loses only 2.5% of its calorific value; this illustrates the imperiousness of unbroken coal to the air. The main deterioration in pillar coal is found, however, to be due to its increased friability resulting chiefly from the heavy pressure to which it has been subjected.

Interesting figures are given by Haldane and Meachem,<sup>1</sup> to show that 80% of the heating which air undergoes while passing through a mine, can be accounted for only by the weathering of the pyrite and the coal itself. Their experiments which are described below were carried out at the Hamstead colliery, South Staffordshire, where the "Thick Seam" is worked at a depth of about 2000 feet below the surface, and their observations and conclusions are so interesting that no apology need be offered for summarizing them at some length.

They noticed that the general effect of opening up the mine was to warm both the coal and the strata adjacent to the workings. The average temperature on the surface at Hamstead is 49° F. At the bottom of the intake shaft the temperature is much more constant than at the surface and averages 60° F. The air is compressed as it descends the shaft and this compression would account for a gain in temperature of 10°. A little moisture is taken up by the air in the shaft, and this must tend to cool the walls so that some heat is transmitted to the air from the strata.

From the pit bottom the air steadily increases in temperature at the rate of about 6° for every 3000 feet. In the workings the temperature is generally about 80° to 85°. In the return airway there is a relatively slow though steady fall of temperature from the face to the upeast shaft. The average temperature in the main north return airway is 77°. Analysis of the air shows that this fall in temperature is probably due to the leakage of air from the intake to the return airway.

To determine the temperature of the undisturbed coal a maximum and minimum thermometer was inserted into the end of a 10-foot borehole in freshly cut coal. The hole was then closed with clay and left undisturbed for at least several days. Several such experiments showed the temperature of the coal to be 66°. Similar experiments were made in coal which had been long exposed. They showed that coal behind such an exposed surface gradually rises in temperature. Thus at two places in the side of a main road the temperature at the ends of 10-foot boreholes were taken in 1894 and 1898. In 1894 the temperatures were 66° and in 1898 they were 93° and 90°.

It was impossible to correctly calculate the total heat generated in the mine since there must have been large radiation losses through the walls, roof and floor. The amount of heat, which escaped by the return airway,

<sup>1</sup> Trans. Inst. of Min. Eng. Vol. 16, 1898, p. 457.

could, however, be calculated. Such a calculation shows that the total heat carried away per minute by the air-current was 48,000 B. Th. U., each cubic foot of air passed through the mine, therefore, carried off with it approximately one B. Th. U. of heat.

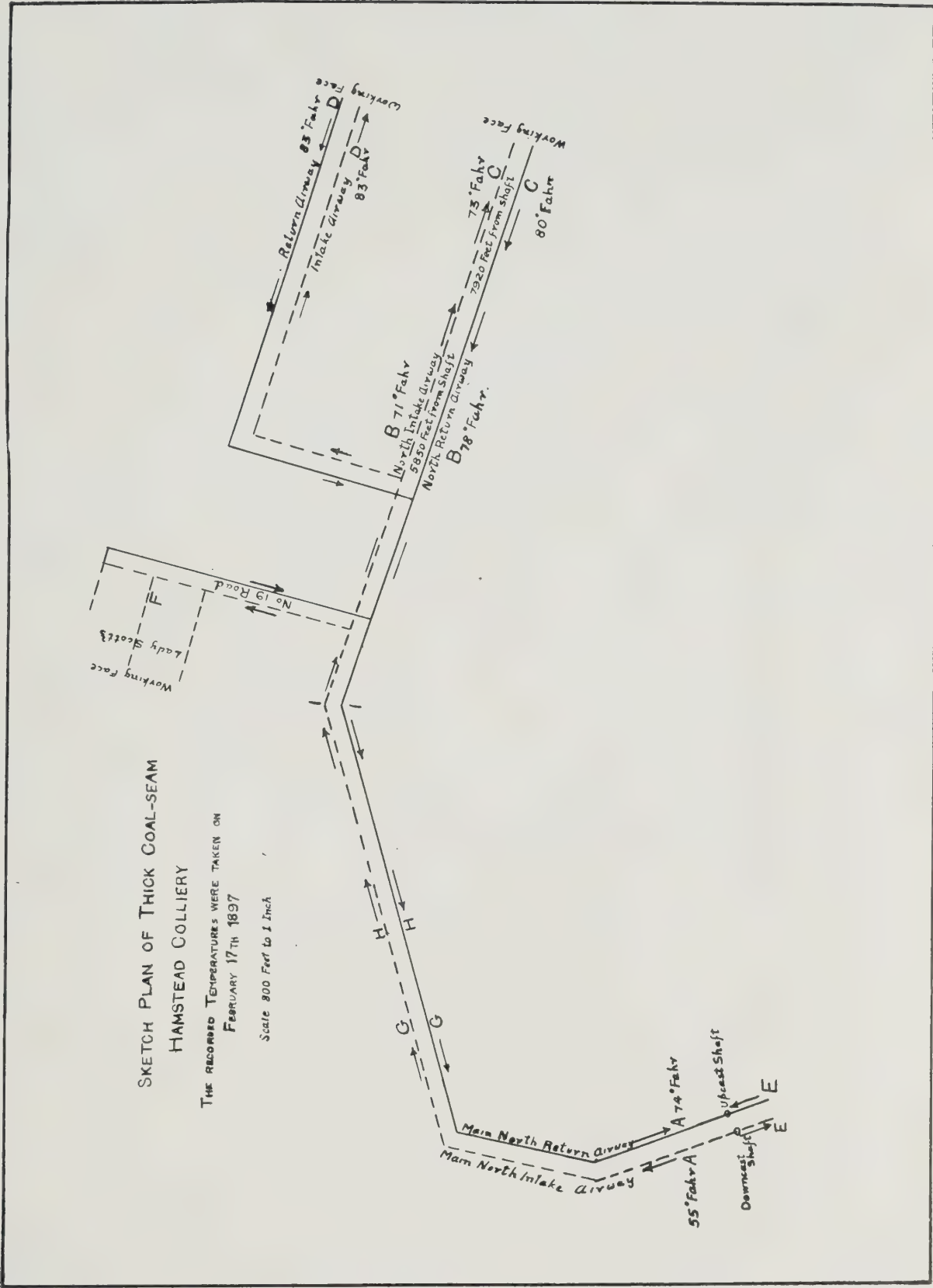
Summarizing Haldane and Meachem's paper further there are several possible sources of heat in a mine. Of these the most obvious are the presence of men and horses and lights. The heat from these sources is, however, approximately determinable and in the case of the particular mine under very careful calculations showed that it could not have exceeded 7% of the heat leaving the mine. Another possible source of heat is the friction due to the settling down of the roof and consequent grinding of the coal and other material by the pressure of the superincumbent strata. The depths of the Hamstead workings is 2,000 feet. Assuming the specific gravity of the strata to be 2, the authors arrived at a pressure of 250,000 lbs. per square foot or about 0·8 tons per square inch. The average output of coal from the north side of the pit was about 15 cubic feet per minute and the average rate of settling down of the strata could not exceed this. The heat liberated could therefore not exceed the heat equivalent of  $15 \times 250,000$  ft. lbs. of work, i.e. 4,850 B. Th. U. Even if this were all given up to the mine air it would only be about 10% of the total heat leaving the mine. The friction of the air current passing through the mine also produces heat,—the amount which could have thus been generated could, however, never exceed 1·7% of the total heat withdrawn from the mine.

It is clear then, that the main portion of the heat generated in the mine was due to some cause other than any of those mentioned, and the obvious conclusion is that it is due to the chemical action of the air on the coal. Haldane and Meachem<sup>1</sup> made a large number of experiments on the subject and a copy of a sketch plan of the entries at Hamstead Colliery is reproduced (Fig. 1) to show the positions of the points where some of the air samples, referred to below, were taken.

Table I shows the analyses of ten samples of air taken in the mine. The figures are calculated by deducting the actual oxygen percentage found from that given by the same gas burette for pure air, and then deducting from the result the deficiency due to dilution with firedamp. For carbonic acid the figures shown are obtained by deducting from the actual result the percentage of carbonic acid in the pure air, (0·030 per cent.)

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<sup>1</sup> Ibid.



(From Haldane and Meachem)

Fig. 1. Map of Hamstead colliery.

TABLE I.

**Analyses of Some Samples of Air Taken in the Mine***(Haldane and Meachem)*

No. and position on plan	Name of road	Distance from shafts	Temperature	Deficiency of oxygen	Carbonic acid in excess	Fire-damp
		Feet	Degs. Fahr.	Per Cent	Per Cent	Per Cent
A.....	Main North Intake Airway.....	150	55	0.00	0.000	0.00
A.....	Main North Return Airway.....	150	74	0.37	0.100	0.06
B.....	North Intake Airway.....	5,850	71	0.16	0.090	0.05
B.....	North Return Airway.....	5,850	78	0.36	0.100	0.06
C.....	Intake Airway.....	7,920	73	0.25	0.095	.....
C.....	Return Airway.....	7,920	80	0.77	{0.250 0.280	0.06
D.....	Intake Airway.....	9,150	83	0.88	{0.310 0.330	0.11
D.....	Return Airway.....	9,150	83	1.70	{0.470 0.470	0.28
E.....	Main South Intake Airway.....	150	55	0.01	0.000	.....
E.....	Main South Return Airway.....	150	.....	0.24	0.095	0.07

This table shows that as the air passes through the mine it steadily loses oxygen and gains carbon dioxide. On the average, however, the oxygen loss is 3.13 times the gain in carbon dioxide. It is very noticeable that the temperature increases with the diminution of oxygen from the air, and Haldane and Meachem's calculations above quoted show this increase to be greater than could be accounted for by friction.

TABLE II.

**Composition of air in mine.***(Haldane and Meachem.)*

Temperature Degs. Fahr.	Deficiency of oxygen	Temperature Degs. Fahr.	Deficiency of oxygen
55	0.00	78	0.36
71	0.16	80	0.77
73	0.25	83	0.88
74	0.37	83	1.70

Two more series of tests similar to the above were made at different times. The results checked those given above very closely except that the percentage of carbon dioxide in the samples taken on January 5 showed a marked increase over that found in previous samples. Haldane and Meachem attribute this to the fact that the barometer was falling on that day, and that this fall caused a flow of gas from old workings.

The absorption of oxygen by anthracite and by bituminous coals in the mine, is clearly demonstrated in a paper by G. N. Burrell.<sup>1</sup> The figures in Table III are for the gases in an enclosed portion of an anthracite mine. This section of the mine was sealed off because of a fire which existed in an adjoining section. The fire did not, in his opinion, affect the particular area from which these samples were obtained, because of a heavy intervening roof fall, consequently the gases represent those trapped and given off normally in a stagnant section, except that one stopping was leaking and some air was entering from the ventilating current. The stopping was tightened and rapid absorption of the available oxygen by the coal ensued, as shown by the third analysis. Four days later the oxygen had dropped to 3 per cent, even though some air was still finding access to the enclosed area.

TABLE III.

## Composition of gases from an enclosed area in an anthracite mine.

(Burrell)

Percentages.						
Sample No.	Date	CO <sub>2</sub>	CO	O <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub>
....1.....	Oct. 31st.....	2.2	0.0	15.0	14.0	68.8
....2.....	Nov. 1st.....	2.3	0.0	14.6	18.1	65.0
....3.....	Nov. 2nd.....	2.6	0.0	6.2	24.2	67.0
....4.....	Nov. 2nd.....	2.9	0.0	5.7	29.3	62.1
....5.....	Nov. 3rd. ....	2.8	0.0	4.1	34.9	58.2
....6.....	Nov. 6th.....	2.6	0.0	3.0	53.0	41.4

The composition of gas from an enclosed area in a bituminous coal mine is shown by Burrell by means of the following analyses, but the conditions as set forth in the following quotations leave one in doubt as to the complete exclusion of the gases from the burning section. The large amount of CH<sub>4</sub> is, however, an indication that Burrell's assumption is correct.

TABLE IV.

## Composition of gases from an enclosed area of a bituminous coal mine.

(Burrell)

Percentages.					
Sample No.	CO <sub>2</sub>	CO	O <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub>
.....1.....	1.50	0.00	0.30	5.29	92.91
.....2.....	1.20	0.00	0.30	5.37	93.13

"A mine fire had once existed in the area and these samples were collected by men with breathing helmets, nine months after the fire had originated and prior to the reopening of the mine. The mine is classed as non-gaseous."

<sup>1</sup> Coal Age, Vol. III, 1913, pp. 104, 110, 143, 147, 194, 311.

This matter of underground weathering is ordinarily of but little importance, so far as the commercial value of the coal is concerned, it is however of immense importance in mining, as a certain amount of broken coal and coal dust is unavoidably left in the workings and abandoned there, and this material and the carbonaceous and pyritic shales often found just over the coal frequently give great trouble by heating and starting underground fires. In some seams spontaneous gob fires are of so common occurrence that special methods of mining have to be employed, and in still other cases the only safe way of operating is to laboriously remove all fine coal and all fallen shale.<sup>1, 2</sup>

The subject of gob fires is exceptionally interesting, but it belongs properly to Coal Mining and its further consideration would be out of place in the present work.

#### WEATHERING LOSSES IN TRANSIT.

Parr and Wheeler sampled some coal at the mine and again a week or so later after transit in cars, and they found deterioration in the order of 100 B.Th.U. for the coals taken, whose value when mined was about 14,600 B.Th.U. It is probable that part of the above loss of calorific power was due to the escape of hydro-carbon gases, but the observers are no doubt right in ignoring this as a factor of importance.<sup>3</sup>

The chief loss, in transit, however, must be due to breakage caused by handling, and, although with the modern equipment now in use by large companies, breakage is greatly reduced, these breakage losses are quite considerable.

In the majority of cases of shipment by rail, the coal does not remain long enough in the cars to suffer any great change, except that of breakage just referred to, but when shipment is made by vessels, and the distances are great; the case is different. As has already been stated in the introduction, the subject of weathering was first brought before the public in connexion with the all too numerous cases of fires in sailing ships carrying cargoes of coal from England to distant ports.<sup>4</sup> Such ships frequently spend months on a single voyage and much of that time is often in the tropics, and unless the coal is an anthracite, or very exceptional precautions are taken, spontaneous fires are almost certain to occur. It is not necessary, however, to deal at length in the present work with this very special subject of coal cargoes, as the causes of heating will be sufficiently considered in the general discussion of weathering, oxidation and storage, while the technical problems of loading and discharging colliers, and of preventing and fighting fires on ship-board, have already been reported on at length by the several Royal Commissions appointed for the purpose.

<sup>1</sup> Lamprecht. Recovery work after Pit fires. 1901—p. 32 and 48.

<sup>2</sup> Morris. T. I. M. E. Vol. XLVII, 1914, p. 195.

<sup>3</sup> White, Bulletin 29, U.S. Bureau of Mines, 1911, pp. 69-70—thinks that lignites and many sub-bituminous coals lose say 200 calories in transit. His figures show losses ranging from  $\frac{3}{4}$  to  $3\frac{1}{4}$  % of total calorific value.

<sup>4</sup> Probably the most detailed and interesting non-official paper on this subject is by Bunning—"The Prevention of Spontaneous Combustion of Coal at Sea"—Trans. North of Eng. Inst. Min. & Mech. Eng'rs., Vol. XXV, 1876, pp. 107-140.

## WEATHERING LOSSES IN STORAGE.

From the work of many experimenters we know that if fresh coal of almost any character be stored in a pile, the temperature of the mass will at first rise. Many kinds of coal never go further than this, in ordinary storage, but gradually cool off again and remain without further marked change for any length of time.

A great variety of coals on the other hand continue to heat, and if nothing be done to ventilate them or otherwise artificially cool them, they ultimately catch fire, and the main purpose of the present report is to discuss the causes of this destructive action and the various methods which have been proposed for its prevention or cure.

In our study of the subject of weathering in greater detail it will be unnecessary to attempt to distinguish any further between action taking place in the mine, in transit, or in storage. In fact it would be impossible to do so satisfactorily as in some cases the character of the coal seam and the method of mining make it possible to get out the coal very promptly, and to place it in the consumers' storage pile while it is still giving off hydro-carbon gases, and has scarcely had time to begin to oxidize. In other cases much of the coal remains in underground pillars for a very long time and even the mined coal is handled slowly and suffers considerable change before it reaches the consumer. It is, therefore, best from the practical point of view to consider the question of weathering as a whole in our further discussion of the subject.



## CHAPTER III.

DISCUSSION OF THE CAUSES OF WEATHERING IN  
GENERAL.

In the following discussion it will be assumed in a general way that the coal has been mined and prepared for the market under ordinary conditions. All weathering which may take place under these circumstances will be included, but as the chief part of the avoidable action occurs in storage the discussion will, to a great extent, be on the storage of coal.

It is impossible to draw any hard and fast line between mere weathering and serious heating even to the point of spontaneous combustion. Both of these phenomena are due to the absorption of oxygen, and as a matter of fact all oxidation whether resulting in little or great rise of temperature, may really be considered spontaneous combustion in an absolute sense.

The most important conditions which influence the weathering of coal in transit and storage are named below, and in so far as is practicable the subject will be discussed under the separate headings in the order given, but the causes of weathering are so numerous and so interdependent that a really systematic and logical treatment of the subject is impossible, and the author craves the indulgence of readers in regard to his presentation of this part of the subject.

## Classification of the Causes of Weathering.

1. The kind of coal (without reference to its inorganic impurities).
2. The time of previous exposure.
3. The presence of moisture.
4. The presence of pyrite and the mechanical condition of the same.
5. The size of the coal.
6. The size, shape, etc., of the storage piles.
7. The initial temperature of storage.

## THE KIND OF COAL.

It is generally believed that anthracite<sup>1</sup> is not liable to spontaneous combustion and this belief is correct in that anthracite will not ignite spontaneously under ordinary conditions. Fayol,<sup>2</sup> however, states and probably with truth, "*que toutes les houilles sont susceptibles de s'échauffer lorsque'elles sont exposée à l'air dans certaines conditions.*" The tendency

<sup>1</sup> The name anthracite is ordinarily used in eastern Canada and the United States for the hard Pennsylvania anthracite only, but other and less stable coals are also entitled to the name. Technically anthracite is a coal having a fuel ratio of over 12.

<sup>2</sup> *Études sur l'Altération de la houille exposée à l'air.* M. Fayol (1879).

of different coals to catch fire is, however, very different. Fayol exposed different kinds of coal to hot air and found that the order of inflammability in air was lignite, bituminous gas coal, bituminous coking coal, and anthracite. This is the same order of inflammability as he found for coals in contact with a flame. He made further experiments using three kinds of coal each one in three different kinds of vessels, namely: a porcelain crucible containing 50 grammes of coal; a rectangular box 12 cms. by 12 cms. by 3 cms; and a cubical box of 12 cms. side.

When exposed to air at  $400^{\circ}$  C. the samples of all the coals caught fire, the lignite easily, and the anthracite after thirty to forty minutes. At  $200^{\circ}$  the bituminous coals did not catch fire except the sample in the large vessel, and the anthracite only when powdered. At  $150^{\circ}$  only the powdered lignite caught fire in all three vessels. At  $100^{\circ}$  only the dust of the lignites and the impalpable powder of the bituminous coal caught fire. At  $75^{\circ}$  none of the coals ignited. (See pp. 53 and 108 for further details).

Fayol's experiment which has been fully confirmed in a general way by numerous observers, proves conclusively that liability to weathering is least in anthracites and greatest in lignites with bituminous coals in an intermediate position, and in a practical sense we may take it that hard anthracite is not appreciably affected by exposure. On the other hand the true lignites suffer so greatly not merely by spontaneous heating, but by dehydration and disintegration, that their storage on a large scale is unlikely to become an important problem for some time in Canada at least. The real practical problem is, therefore, to be found in a study of bituminous and semi-bituminous coals, and the remainder of this paper will deal almost exclusively with coals of this character.

Bituminous coal—ranging as it does from semi-lignite to semi-anthracite—falls itself within Fayol's conclusions, and there is a very evident decrease in liability to serious weathering as we go up in the scale toward the anthracites, but we find very great individual variations in coals of substantially the same grade. These variations are due largely to differences in friability, but are also due in part to the presence or absence of small quantities of very easily oxidized substances such as the resins. The amount and character of mineral impurities also play a part.

It should be noted that the term "anthracite" is used to describe a considerable range of coals and that some so-called "anthracites" are sufficiently close to bituminous coals to be liable to weathering and even to considerable heating if stored under particularly unfavourable conditions; for instance certain very valuable Welsh smokeless coals often spoken of as anthracites, have been found unsuitable for shipment in large quantities to or through the tropics; these cases, however, are somewhat aside from the scope of the present investigation.

The purity of a coal, that is to say its relative freedom from inorganic matter, is no longer generally considered to be an indication of its comparative immunity from weathering, except that one particular impurity—

pyrite—is still believed by many to be one of the main causes of trouble. With the exception of pyrite, which will be specifically dealt with later, it is now believed by many observers<sup>1</sup> that the presence of considerable amounts of ordinary ash-forming impurities is likely to lessen the rate of weathering of the coal, although this must depend to a large extent on the character of the impurities themselves. The fact that the impure coals are often less liable to spontaneous combustion is no doubt due to the fact that the mineral matter often occurs in the form of thin plates in the cleavage planes, thus coating and protecting a considerable part of the surface of the coal proper when it is broken. It is also probable that pure are, generally speaking, softer than impure coals, and therefore more easily reduced to dust.

The differences in the rate of weathering of coals of substantially the same class are shown by Porter and Ovitz who experimented with coals in a current of 50% oxygen at 140° to 160° C. The results of their experiments are shown in the appended figure (Fig. 2), and admirably illustrate the individuality of these coals.

#### TIME OF PREVIOUS EXPOSURE.

In many cases coal is subjected to a more or less extended storage in piles at the mines and in coal-cars in transit, and is then stored in considerable quantities by the distributing agents or consumers. In such a case there is usually less likelihood of heating in the final storage, as the only surfaces which will be attacked by oxygen with any marked energy are those new faces caused by breakage in handling. As an example of this we have the case of very large quantities of coal which are mined and stored in eastern Canada during the winter, then shipped during the summer season of navigation to Montreal for storage until the following winter. Such coal, although piled the second time in hot weather, is much less likely to heat than freshly mined coal stored under similar conditions.

Parr and Wheeler<sup>2</sup> find the loss of a coal during the second year of storage to be only one-half that occurring during the first year.

An experiment made by Porter and Ovitz<sup>3</sup> shows the effect of previous exposure upon absorption of oxygen. Fine coal was used and the exposure was but short, yet the results may be taken as an indication on a small scale of what happens more slowly in a large pile. (Curve C, Fig. 13).

#### THE EFFECT OF THE PRESENCE OF MOISTURE.

From the Reports of the Royal Commissions on Coal Cargos in England (1876) and in New South Wales (1897) one might conclude that coal containing much moisture would be likely to heat badly; yet out of 26 persons

<sup>1</sup> Dennstedt and Bünz found that coals which were most free from mineral matter were on the whole more readily oxidized than impure coals and increased in temperature more rapidly when exposed to air. See *Zeitschrift für Ang. Chemie*, Vol. XXXV, 1908, p. 1825.

<sup>2</sup> Univ. of Illinois Eng. Exp. Sta. Bull. 38, 1909.

<sup>3</sup> U. S. Bur. of Mines Tec. paper No. 16, 1912.

Int. Cong. of Appl. Chem. Vol. 10, 1912, p. 251.

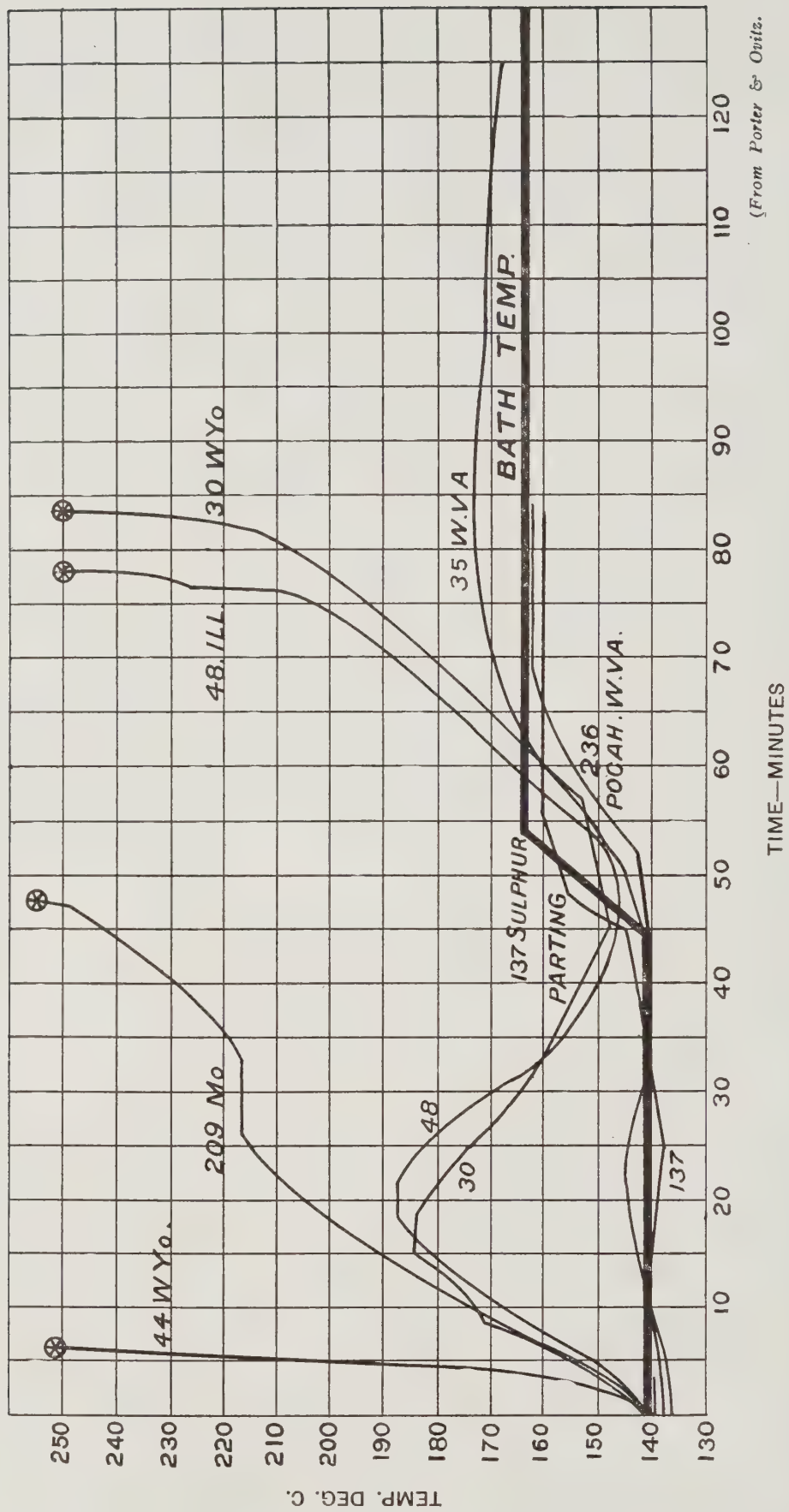


FIG. 2. Behaviour of coals in a current of 50 per cent oxygen at 140° and 160°C. Rate of flow of oxygen—4 litres per hour.

who in 1876, testified to the injurious effects of moisture, 25 admitted on cross-examination that they were simply repeating hearsay, and the other remaining witness was not available for cross-examination; furthermore, although the bulk of the testimony in 1897 was apparently to the same effect, the conclusions of the Commission did not give it much weight.

One would naturally expect that a coal containing moisture would be retarded in its heating because, until all the moisture has been evaporated, the temperature cannot give rise above 100°C. Yet, on the other hand, the steam percolating through the surrounding mass, and condensing in the cooler parts, will heat as well as moisten them, and may thus tend to hasten oxidation in those parts.

Richters<sup>1</sup>, one of the ablest of the early students of coal weathering, who worked from 1867 to 1870, made some experiments to determine whether moisture aided or retarded the absorption of oxygen by coal. He took two tubes and placed air-dried coal in one and moist coal in the other, both coals being freshly mined. The air-dried coal absorbed oxygen more quickly than the moist coal. He also found that by placing small bulbs containing fused calcium chloride alongside the dry sample of coal, so that it became gradually drier, the rate of absorption was increased. The same phenomenon was observed when coal was used which had been dried for a day over sulphuric acid, although this coal must already have absorbed a considerable amount of oxygen while drying. It would seem that these experiments definitely prove that moisture hindered the absorption of oxygen by the coal in question, but this is not in accordance with the results of recent experiments by Porter and Cameron<sup>2</sup> and, furthermore, there is no doubt that moisture will increase the rate of oxidation of pyrite, and whether the net results will be an increase or decrease in the final temperature must depend on the amount of pyrite present and on the amount of moisture.

Fayol<sup>3</sup> made a number of experiments in order to determine the effect of moisture on Commentry coal. The coal was tested in three different conditions:—

1. Freshly won fines.
2. The same coal previously dried in ovens at a temperature not exceeding 40°.
3. The same coal not dried, but sprinkled to make it damp, but not wet.

A sufficient number of piles of each material were made to last the winter. These piles contained from 2 to 12 cubic metres each and were built, some on the surface under open sheds, and the remainder in dry levels, underground. Temperature observations were made every day in each pile for several months, and the behaviour of the different piles of the same

<sup>1</sup> Dingers Poly. Jour. Vol. 190, 1868, p. 398.

Dingers Poly. Jour. Vol. 193, 1869, pp. 54 and 264.

Dingers Poly. Jour. Vol. 195, 1870, pp. 315 and 449.

<sup>2</sup> See page 144 et seq.

<sup>3</sup> Études sur l'altération de la houille exposée à l'air. M. Fayol, 1879, p. 155.

level, both wet and dry, was almost identical. In no case did any one of the piles rise to a temperature above 50°.

Parr and Kressmann<sup>1</sup> conducted some experiments with both dry and thoroughly wet coal, which they studied at elevated temperatures—40°, 60°, 80°, and 115°C.—and their work at first sight appears to contradict that of Fayol described above.

They say that without exception in all of their series of tests “wetting the coal increased the activity as shown by the ultimate temperature.” Their statement is of course correct as applied to their tests, but it must be remembered that their samples were “stored” for a total of 12 days at elevated temperatures, which were raised in stages by external heat from 40°C. to 60°, and 80° and finally to 115°C. irrespective of any additional heating due to their own oxidation. A study of their results would seem to show that the wet coals did not heat on their own account as much as the dry ones until this externally applied heat raised them above 80°C. a temperature which is fatal to many coals. They also note that the coals tested, while typical of their district, are of very unusual composition, being high in sulphur and exceptionally high in moisture<sup>2</sup>. The hand picked lump coal tested had 1·29% sulphur and 4·62% moisture, and the run-of-mine a great deal more of these constituents.

Porter and Ovitz<sup>3</sup> in a brief, but very valuable report to the United States Government, conclude that:—

“In not one of the many cases of spontaneous combustion found by the authors, could it be proved that moisture had been a factor. Still the physical effects of moisture on fine coal, such as close packing together of dust or small pieces, may in many cases aid spontaneous heating.”

Cox<sup>4</sup> quotes Doane as saying that moisture is an indication of the liability of coal to heat; he then points out that combined water is an indication of the grade of a coal, and as upon the grade of coal depends liability to heat, so moisture in the sense of combined water “does increase the heating.” The use of the term moisture in this sense is, however, unusual and misleading and there is little evidence that moisture in the true sense has any effect in the majority of cases.

In conclusion it may be said that in all probability the temperatures of ordinary coals under ordinary conditions of storage are not raised to any appreciable extent by moisture. The question naturally arises, what was the basis of the once prevalent belief that moisture was an important factor in spontaneous heating?

This belief is, no doubt, chiefly due to the confusion of cause and effect on the part of persons who have discovered fires in coal storage. It is commonly observed that fires or hot spots in the pile are discovered shortly after rain storms, and that nearly always a hot spot is surrounded by damp or wet coal even if the main part of the pile is dry. The first case is easily

<sup>1</sup> For fuller description of Parr and Kressmann's work see pp. 37-40, 42, 109-110.

<sup>2</sup> In this connexion see Cox, just below and on p. 58.

<sup>3</sup> Tech. Paper, No. 16, U. S. Bureau of Mines, 1912.

<sup>4</sup> Internat. Cong. App. Chem. Vol. X, 1912, p. 109.

explained by the fact that dry coal is so poor a conductor that the surface of a pile may show no indication of a hot spot or even an incipient fire in the interior. A rain storm would however provide moisture enough to soak into the pile, and this moisture on approaching the hot spot would be turned into steam which would work its way back to the surface and be observed, thus attracting attention to the hitherto unsuspected heating. The second explanation is equally simple. Air dry coal always contains some moisture, and in lignitic coals there is also a very considerable amount of combined water. In the case of a hot spot in the interior of a pile this moisture is driven off, either escaping at the surface as steam, or condensing on the cooler coal in the neighbourhood. Added to this there is of course an actual formation of water when the hydrogen constituents of coal are oxidized.

As an illustration of the second case it may be noted that during the experiments of the author at Outremont and Glace Bay (see pp. 154-164) vapour or condensed moisture was always noticed in the observation tubes in the neighbourhood of hot spots even when the temperature was far below the boiling point.

#### PRESENCE OF PYRITE.

The presence of pyrite may affect the weathering of coal in two<sup>1</sup> ways:—

- (a) By disintegration of the coal due to the slow oxidation of pyrite.
- (b) By actual generation of enough heat when oxidized to warm up the coal surrounding it to a dangerous extent.

#### Disintegration Due to Weathering of Pyrite.

That pyrite causes disintegration of coal on weathering is well known, and the fine coal thus produced, undoubtedly increases the tendency of the mass to heat, but it is difficult to get any very definite measure of the effect, as other causes also result in disintegration. The action in brief is that pyrite in the presence of moisture and oxygen is more or less completely converted into oxide and sulphate of iron with the simultaneous production of appreciable quantities of sulphuric acid. This acid in time attacks the carbonates of lime and magnesia which are usually present in the cleavage and joint planes of the coal, converting them into sulphates.<sup>2</sup> These chemical reactions all involve increase in bulk followed often by shrinkage due to the solution of the soluble sulphates produced. Thus the coal on the whole suffers a much greater degree of disintegration than might at first be expected from the small amount of pyrite oxidized, which in ordinary cases does not exceed from 10 to 25% of the total pyritic matter in the coal, i.e., a small fraction of 1% of the total.

<sup>1</sup> In addition to the two very important effects of pyrites noted above, it is quite possible that it may contribute to weathering in still other, although less important ways, such as catalytic action, etc. Dennestedt and Bünz—Zeit. fr. Ang. Chemie. Vol XXXV, 1908, p. 1825, discuss the possibility of catalytic action being a factor in weathering and ultimately dismiss it as likely to be of little or no effect.

<sup>2</sup> This was probably first noted by J. P. Kimball. Trans. Am. Inst. Min. Engrs. Vol. VIII, 1879, p. 207.

The most valuable information available bearing on the extent of the disintegration of coal due to weathering is the result of some experiments by **S. W. Parr** and **W. F. Wheeler**. The coals tested are the same as those used for their main experiments, described at length on pp. 69-86.

Tables V and VI, copied from Parr and Wheeler, show that the proportion of small sizes in the nut coal increased considerably due to the action of weathering, and that the average diameter decreased proportionately.

The disintegration was no doubt largely due to the oxidation and swelling up of the pyrite as already stated, but it was also due partly to the action of frost, both of these causes acting in conjunction with the oxidation of the coal proper and the disintegration produced thereby. In the case of the Vermilion county nut coal the amount of coal that would pass through a half-inch hole was nearly doubled. The figures for the nut coal from Williamson and Sangamon counties show that there was seven times as much coal below half-inch diameter after one and one-half year's storage as was originally present. The average diameter of the pieces of coal in all these lots was about three-fourths as great after storage as before, the average weight being only about 40% as great.

The changes in the screenings were not so great as in the nut coal, but they were probably of as much, or more importance in the matter of affecting the economic value of the coal and its liability to give trouble.

TABLE V.  
Sizing Test Showing Disintegration of Nut Coal.

(Parr and Wheeler)  
Vermilion County, Illinois.

Round hole screen		Original sizes		Exposed bins 1½ years		Covered bins 1½ years	
Through. Inches	Over. Inches	Per cent	Cumula- tive per cent	Per cent	Cumula- tive per cent	Per cent	Cumula- tive per cent
3	1	66.2	....	42.5	....	44.2	....
1	$\frac{3}{4}$	5.0	71.2	8.0	50.5	7.6	51.8
$\frac{3}{4}$	$\frac{1}{2}$	7.2	78.4	11.8	62.3	11.7	63.5
$\frac{1}{2}$	$\frac{3}{8}$	4.0	82.4	6.9	69.2	6.7	70.2
$\frac{3}{8}$	$\frac{1}{4}$	4.0	86.4	6.8	76.0	7.1	77.3
$\frac{1}{4}$	$\frac{1}{8}$	5.0	91.4	10.9	86.9	10.4	87.7
$\frac{1}{8}$	0	8.6	100.0	13.1	100.0	12.3	100.0
Total.....	..	100.0	....	100.0	....	100.0	....
Average diameter.....1.458 inches				1.074 inches		1.102 inches	

Williamson County, Illinois.

3	1	94.0	....	70.2	....	68.5	....
1	$\frac{3}{4}$	1.6	95.6	5.7	75.9	5.7	74.2
$\frac{3}{4}$	$\frac{1}{2}$	1.8	97.4	6.6	82.5	7.1	81.3
$\frac{1}{2}$	$\frac{3}{8}$	0.7	98.1	3.1	85.6	4.1	85.4
$\frac{3}{8}$	$\frac{1}{4}$	0.5	98.6	3.2	88.8	3.6	89.0
$\frac{1}{4}$	$\frac{1}{8}$	0.5	99.1	4.6	93.4	4.9	93.9
$\frac{1}{8}$	0	0.9	100.0	6.6	100.0	6.1	100.0
Total.....	.....	100.0	....	100.0	....	100.0	....
Average diameter.....1.910 inches				1.532 inches		1.506 inches	

Sangamon County, Illinois.

3	1	89.4	....	64.3	....	52.0	....
1	$\frac{3}{4}$	4.1	93.5	6.9	71.2	9.3	61.3
$\frac{3}{4}$	$\frac{1}{2}$	3.5	97.0	8.4	79.6	10.8	72.1
$\frac{1}{2}$	$\frac{3}{8}$	1.2	98.2	3.2	82.8	5.7	77.8
$\frac{3}{8}$	$\frac{1}{4}$	0.6	98.8	4.0	86.8	5.8	83.6
$\frac{1}{4}$	$\frac{1}{8}$	0.6	99.4	7.4	94.2	8.1	91.7
$\frac{1}{8}$	0	0.6	100.0	5.8	100.0	8.3	100.0
Total.....	.....	100.0	....	100.0	....	100.0	....
Average diameter.....1.854 inches				1.442 inches		1.252 inches	

TABLE VI.  
Sizing Test Showing Disintegration of Screenings.  
(Parr and Wheeler)  
Vermilion County, Illinois.

Round hole screen		Original sizes		Exposed bins 1½ yrs.		Covered bins 1½ yrs.	
Through. Inches	Over. Inches	Per cent	Cumula- tive per cent	Per cent	Cumula- tive per cent	Per cent	Cumula- tive per cept
1¾	1	19.0	....	11.3	..	11.6	....
1	¾	8.9	27.9	6.3	17.6	6.3	17.9
¾	½	14.8	42.7	12.9	30.5	12.2	30.1
½	⅜	8.5	51.2	9.3	39.8	9.3	39.4
⅜	¼	11.1	62.3	11.8	51.6	11.8	50.2
¼	⅛	16.4	78.7	21.0	72.6	21.0	71.2
⅛	0	21.3	100.0	27.4	100.0	27.8	100.0
Total.....		100.0	....	100.0	....	100.0	....
Average diameter.....0.548 in.				0.425 in.		0.425 in.	

Williamson County, Illinois.

1-¾	1	18.9	....	19.0	....	14.2	....
1	¾	9.0	27.9	9.2	28.2	7.0	21.2
¾	½	14.4	42.3	15.4	43.6	13.0	34.2
½	⅜	8.5	50.8	9.5	53.1	9.0	43.2
⅜	¼	10.4	61.2	10.6	63.7	11.4	54.6
¼	⅛	15.4	76.6	17.0	80.7	20.2	74.8
⅛	0	23.4	100.0	19.3	100.0	25.2	100.0
Total.....		100.0	....	100.0	....	100.0	....
Average diameter.....0.542 in.				0.557 in.		0.466 in.	

Sangamon County, Illinois.

1-¾	1	38.8	....	15.1	....	15.6	....
1	¾	7.9	46.7	9.3	24.4	9.1	24.7
¾	½	13.2	59.9	15.6	40.0	15.6	40.3
½	⅜	6.6	66.5	7.7	47.7	9.7	50.0
⅜	¼	7.2	73.7	9.4	57.1	11.5	61.5
¼	⅛	11.2	84.9	17.2	74.3	19.6	81.1
⅛	0	15.1	100.0	25.7	100.0	18.9	100.0
Total.....		100.0	....	100.0	....	100.0	....
Average diameter.....0.768 in.				0.498 in.		0.518 in.	

### Heating due to Oxidation of Pyrite.

The fact that pyrite evolves heat on oxidation is universally acknowledged, but the extent to which this affects a large storage pile is a matter upon which there is great difference of opinion. It has been stated by some authorities that the heat generated by the oxidation of pyrite is the primary cause of spontaneous combustion. Thus, although the first authoritative report<sup>1</sup> on the subject had concluded that the presence of pyrite in the coal was of secondary importance, and Blackwell<sup>2</sup> and others had supported this view, yet the English Royal Commission<sup>3</sup> (1875) appointed to investigate the carriage of coal on board ships, gave the causes of spontaneous combustion in order of importance as follows:—

1. The oxidation of pyrite which the coal contains.
2. The absorption of gas and notably of oxygen by the coal dust.
3. The oxidation of carbon and of certain compounds which are present in the coal.

M. Haton de la Goupilliere<sup>4</sup>, in a report of the French Firedamp Commission, states that oxidation of pyrite, or of certain organic substances in coal is often the primary cause of spontaneous combustion. This and many other opinions expressed in that report seem, however, to be offered without very firm convictions.

In **Fayol's**<sup>5</sup> experiments which are referred to on pp. 25, 52, and 108, it was found that the amount of oxygen absorbed was not proportional to the amount of pyrite in the coal, hence some of the oxygen must have been absorbed by the coal. Fayol found in fact that the pyrite in the Commentry coal does not oxidize as quickly as the coal itself; in dry air the pyrite is not oxidized at all, and in moist air only slowly.

Many observations of actual facts tend to show that the oxidation of pyrite is not the primary cause of spontaneous heating. Thus Dr. Percy<sup>6</sup> notes that no coal in Great Britain is so liable to spontaneous combustion as the ten yard or thick coal of South Staffordshire, which only contains a small amount of pyrites, usually equivalent to not more than 0·5 per cent of sulphur. Percy had already expressed this opinion in his lectures at the Royal School of Mines, and in a paper in 1864 in *Chemical News*.

**Richters**<sup>7</sup> calculated the heat which could be evolved by a coal containing 1·01 per cent of pyrite. He showed, by reference to Dulong's experiments on heats of combustion, that in this case, under the most favourable assumptions regarding pyritic combustion, the temperature of the coal could not possibly be raised more than 72°C. He assumed in this calculation that the heat of oxidation of pyrite is the same as would

<sup>1</sup> De la Beche and Playfair—"Steam Coal for the Royal Navy," London, 1846 (1848-51).

<sup>2</sup> Trans. North Eng. Inst. Min. & Mech. Eng., Vol. X, 1861, pp. 161-7, 192-3.

<sup>3</sup> Report of Eng. Royal Commission on "Spontaneous combustion of Coal in Ships," 1876.

<sup>4</sup> Rapport de la Comm. d'étude des Moyens propre a prévenir les Explosions de Gison, 1878.

<sup>5</sup> Etude sur l'Altération de la houille exposée à l'air, 1879.

<sup>6</sup> Metallurgy, Percy, Vol. Fuel, 1875, pp. 289-298.

Dinglers Poly. Journ. Vols. 190, 193, 195,—1868-9-70.

be produced by the combustion of the iron and of the sulphur separately. This, as he no doubt well knew, is a vastly excessive assumption. He further assumed that the combustion takes place instantaneously, and that all of the heat produced is used in raising the temperature of the coal. In actual fact, the oxidation of the pyrite requires a long period for its completion. On the other hand he assumed the pyrite to be uniformly distributed through the coal, whereas it occurs in lumps which might be conceived to become local centres of combustion. Richters thus arrived at the conclusion that the pyrites ordinarily present in coal could not be more than a secondary factor in its spontaneous combustion.

Richters also experimented with a mixture of pyrites and quartz sand, which he submitted to the action of oxygen. His results do not strengthen the theory that pyrite is the cause of spontaneous heating, because it was found to absorb very little oxygen. For a description of his experiment see pp. 59-62, and 103-108.

**Kimball**<sup>1</sup> points out the importance of distinguishing between pyrite and marcasite, owing to the greater ease with which the latter weathers; if much of the so-called pyrites in coal is really marcasite, then sulphides in coal may have a greater influence on heating. This observation although made many years ago has apparently been overlooked by most experimenters, who apply the term pyrite to both pyrite proper and marcasite without distinction. Almost the only recent reference to the matter is in a paper by Lamplough, see p. 42.

**Lewes**<sup>2</sup> does not believe that pyrite, scattered through a mass of coal, and undergoing slow oxidation, can raise the temperature of the coal to the ignition point. He points out, however, that pyrite may increase the liability to ignition, when present in large quantities, by liberating sulphur. The ignition point of sulphur is 250° C, over 100° C below the ignition point of coal.

Sulphur in coal is mainly present as either pyrite or marcasite. Some coals contain large nodules of pyrite, while others contain the pyrite very finely disseminated along planes of weakness in the coal; it may also be disseminated finely throughout the whole mass.

Experimenters appear to be universally agreed upon the fact that particles of pyrite expand on weathering, thus breaking up the enclosing coal into smaller sizes, and exposing new surfaces to the air. The main point about which opinions seem to differ widely, is the importance of the heat set free due to the oxidation of pyrite.

"Sulphur balls" are known to find their way frequently into coal piles, but the surface of such a ball of pyrite would soon become oxidized, after which there would be very little reaction. To generate sufficient heat to materially affect the surrounding coal, one would imagine that finely disseminated particles, having large area in comparison with their size, would

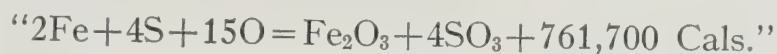
<sup>1</sup> Trans. Am. Inst. Min. Engrs. Vol. VIII, 1879, pp. 204-225.

<sup>2</sup> T. I. Naval Architects. Vol. 31, 1890, pp. 204-228.

Abstract Journ. Soc. Chem. Ind. Vol. IX, 1890, pp. 483-5.

be necessary, and coals containing considerable quantities of fine pyritic matter do in fact often fire spontaneously underground.

**Haldane and Meachem**<sup>1</sup> made an approximate calculation of the heat which might be generated underground in a colliery, assuming, for the sake of argument, that the total shortage of oxygen in the upcast air is all due to the oxidation of the pyrite. As no data were available for the heat of combustion of iron pyrite they followed Richters, and took the heats of combustion of the sulphur and iron separately, thus:—



That is for every  $15 \times 16$  lbs. of oxygen used enough heat is generated to raise the temperature of 761,700 lbs. of water  $1^\circ$  centigrade. Hence, 5,700 B.Th.U. are formed per lb. of oxygen absorbed. In the north side of the mine 295 cubic feet of oxygen were consumed per minute and, therefore, since 1 cubic foot of oxygen at the pit bottom weighs 0.09 lb., the total heat production per minute on the above assumption, would have been  $295 \times 0.09 \times 5,700$  or about 150,000 B.Th.U. By calculation it was found that the air current from the north side carried away about 48,000 B.Th.U. per minute. The surplus, about 100,000 B.Th.U. per minute, went partly into the surrounding strata and partly into the coal.

The above calculation gives the benefit of every doubt to the pyrites, but it shows that in a large mine a very considerable amount of heat may conceivably be generated by the oxidation of pyrites. It must be remembered, however, that this heat is distributed over an immense surface, and that by far the greater part of it is conducted away into the mass of virgin coal, and the rock strata above and below the seam. As a matter of fact it is extremely improbable that all, or even the main part of the oxygen absorbed in a coal mine, goes into combination with pyrites. Most of it probably combines with the carbonaceous matter of the coal itself. This does not better matters so far as heating is concerned as carbon has a higher calorific power than sulphur and iron, but it relieves the pyrites of a large share of the responsibility.

The effect of pyrite has recently been studied by **Parr and Kressmann**.<sup>2</sup> They made numerous experiments on coal from Williamson county, Illinois. Lumps were selected, crushed and screened into three sizes:— $0-\frac{1}{8}$  inch,  $\frac{1}{8}-\frac{1}{4}$  inch,  $\frac{1}{4}-\frac{3}{4}$  inch. A portion of the finest size was further pulverized in a ball mill until it went through an 80-mesh screen and 75% of it through 120-mesh screen; thus four groups were made, which in the following discussion will be called size 0, size  $0-\frac{1}{8}$ , size  $\frac{1}{8}-\frac{1}{4}$ , size  $\frac{1}{4}-\frac{3}{4}$ .

The sized samples were analysed and portions set aside for experiment as they stood. Other portions had pyrite added to them in known quantities, thus giving lots of each size which were identical in all respects but pyritic contents.

<sup>1</sup> T. I. M. E. Vol. 16, 1898, p. 457.

<sup>2</sup> Univ. of Illinois. Eng. Expt. Station, Bull. No. 46, 1910.

The tests were conducted in four constant temperature ovens maintained at 40°, 60°, 80°, and 115° centigrade, respectively. The coal was first placed in the 40° oven, and after a period of three days was moved to the 60° oven where it was left for three days and so on. Thus each sample remained three days in each oven. Each sample was contained in a five gallon stone jar, whose bottom was perforated with  $\frac{1}{2}$ -inch holes. A jar of this size held thirty-five or forty pounds of coal. Air at the temperature of the oven was allowed to circulate freely around the jar. The temperature of the samples was observed periodically by means of thermometers fixed in the coal and projecting out through the cover of the oven, and the difference between this observed temperature and that of the oven at the end of each three day period was tabulated and plotted.

The composition of the coal used in the experiments is indicated by proximate analyses as follows:—

TABLE VII.

**Composition of Williamson Co., Illinois, Coal used by Parr & Kressman.**  
(Parr and Kressman)

	Size 0 and 0- $\frac{1}{8}$	Size $\frac{1}{8}$ - $\frac{1}{4}$
Moisture.....	4.16%	4.62%
Volatile matter .....	33.48 "	33.37 "
Fixed carbon .....	50.86 "	50.88 "
Ash.....	11.50 "	11.13 "
Total.....	100.00 "	100.00 "
(Sulphur) .....	1.26 "	1.29 "

*Calculated to Dry Coal.*

Volatile matter .....	34.92%	34.78%
Fixed carbon .....	53.08 "	53.58 "
Ash.....	12.00 "	11.64 "
Total.....	100.00 "	100.00 "
(Sulphur) .....	1.32 "	1.35 "

The pyritic iron was determined by calculation from the difference between the total iron in the coal and the iron soluble in dilute hydrochloric acid. The results for the above two samples are as follows:—

TABLE VIII.

**Composition of Williamson Co., Illinois, Coal used by Parr & Kressman**  
(Parr and Kressman)

	Size 0- $\frac{1}{8}$	Size $\frac{1}{8}$ - $\frac{1}{4}$
Total iron .....	1.91%	1.73%
Soluble iron.....	0.73 "	0.67 "
Pyritic iron.....	1.18 "	1.06 "
Calculated pyrite content.....	1.76 "	1.60 "

Inasmuch as more of the larger size was used than of the fine, the average pyrite content of the coal was taken as 1.65 per cent.

The pyritic content of the samples was increased as follows. Large lumps of pyrite were taken just as they occurred in the coal measures of Vermilion county. These lumps were ground to pass through a 20-mesh sieve. The purity was determined to be 87.62 per cent by calculation from the sulphur content which was 46.73 per cent.

The experiments were made as follows: four jars were filled with the coal using one of the four different sizes in each jar. These were placed one in each oven in the same increasing ratio of size of coal to temperature of oven. Thus size 0 and size  $0-\frac{1}{8}$  were put in the  $40^\circ$  oven, size  $\frac{1}{8}-\frac{1}{4}$  in the  $60^\circ$  oven, size  $\frac{1}{4}-\frac{3}{8}$  in the  $80^\circ$  oven, and size  $\frac{3}{8}-\frac{3}{4}$  in the  $115^\circ$  oven. Each jar was left in the oven for three days and then moved to the next hotter oven. This method of procedure saved a considerable amount of time and was carried out after it was found that the larger sizes were not appreciably oxidized at the lower temperatures.

Parr and Kressman give an elaborate series of tables and curves showing the results of their numerous tests, and from these they draw conclusions from which we may summarize the following:—

a. Oxidation is greatly accelerated and in certain phases is directly dependent upon an increase of temperature.

b. Coal in a fine state of division heats much more rapidly than coarser sizes of the same material, and this oxidation is in the beginning largely due to the absorption of oxygen by “unsaturated compounds, the products being humic acids or other fixed constituents of the coal texture.” This oxidation “does not result in the formation of carbonic acid.”

c. The presence of pyrite in the coal is a “positive source of heat” due to oxidation of the sulphur; “this may be considered the second stage in the process of oxidation.” But in coals of the Illinois type “with their high per cent of sulphur” the pyritic oxidation is of greater importance than the oxidation of the coal matter proper, particularly as these coals carry much duff or dust, which is largely pyritic.

d. Moisture is essential to pyritic oxidation, and under the circumstances of their tests it was found that in all cases “wetting the coal increased the activity as shown by the ultimate temperature.”<sup>1</sup>

e. The oxidation of carbon and hydrogen takes place at temperatures in excess of  $120^\circ$ , and may be considered a third stage.

The above very condensed statement of Parr and Kressman’s work does not by any means cover the whole of the ground of which they treat, and the author has therefore prepared the following six curves from their data with a view to presenting in a summary form the results of their experiments on the effect of pyrite.

As fine coal proved much more susceptible to oxidation these redrawn curves only include the three smallest sizes.

<sup>1</sup> This conclusion will receive consideration in its proper connexion.

Parr and Kressman's work is undoubtedly of great value, but, as has already been noted, and as they point out in their paper, the Illinois coal on which they worked is very different from ordinary bituminous coal in that it is exceptionally high in sulphur and contains from two to four times as much combined water. Their conclusions therefore should not be too freely applied to ordinary coal.

Fig. 3, A, B, and C show the effect of pyrite on the three sizes of coal. In Fig. 3 A the final temperature of the coal with 3% pyrite is given, but, as a matter of fact, this very fine coal had heated to a maximum of 75° in 30 hours and then cooled again to 46° before the end of the 3 day period. If the mean of its maximum and final temperatures be taken there is a gradual increase in the heat developed as the pyrite content of the coal increases. Fig. 3 B shows an increase in temperature rise as the percentage of pyrite in the coal increases. Fig. 3 C shows the same results, but less definitely. Figures 3 D and 4 A and 4 B show the results of a similar series of tests with wet coal. Fig. 3 D shows that for very fine coal the pyrite has a marked effect. Coal with 1.6 per cent of pyrite did not catch fire, whereas the coals with 3% and 5% of pyrite, respectively, ignited in the 115° oven. Neither Fig. 4 A nor 4 B shows any very different increase in rise of temperature due to the pyritic content of the coal. It is possible, however, that this may be due to the difficulty of keeping each sample thoroughly wet with the same amount of moisture and to the fact that any heat generated, while the coal is still damp, is used up in drying the coal instead of in raising its temperature. Figures 4 C and 4 D show tests with unscreened coal, Fig. 4 C with dry coal, and Fig. 4 D with wet coal. These curves show very definitely that an increase of the pyrite content from 1.4% to 3% produces a marked increase in rise of temperature. A further increase of the pyrite to 5%, however, does not seem to produce much effect.

Porter and Ovitz<sup>1</sup> separated a coal containing 3.34% sulphur into a lighter portion containing 2.64% sulphur, and a heavier portion containing 5.33%. "The heavier portion showed no greater tendency to develop heat in the oxidation test." It must be noted, however, that this test was made upon dried coal and that the oxidation of sulphides of iron at the temperature used probably does not take place at all except in the presence of moisture. Their figure, illustrating this experiment, is appended as Fig. 5.

Lamplough and Hill<sup>2</sup> experimenting quite recently with a number of English (Barnsley) coals find that in the case of certain "soft" i.e. powdery Barnsley coals which contain much finely divided "pyrites", the oxidation of this material "might possibly be the predominant factor in the spontaneous combustion of such coal dust". Their experiments and conclusions are summarized in some detail on pp. 111-114, and are very interesting, but so far as pyrite is concerned they are not very conclusive. They particularly call attention to the fact that they used the word "pyrites" to designate sulphide of iron, FeS<sub>2</sub>, without prejudice as to its nature, but that an exami-

<sup>1</sup> International Congress of Applied Chemistry, 1912. Vol. X, pp. 251-267.

<sup>2</sup> Trans. Inst. Min. Engrs. Vol. XLV, 1913, pp. 629-657.

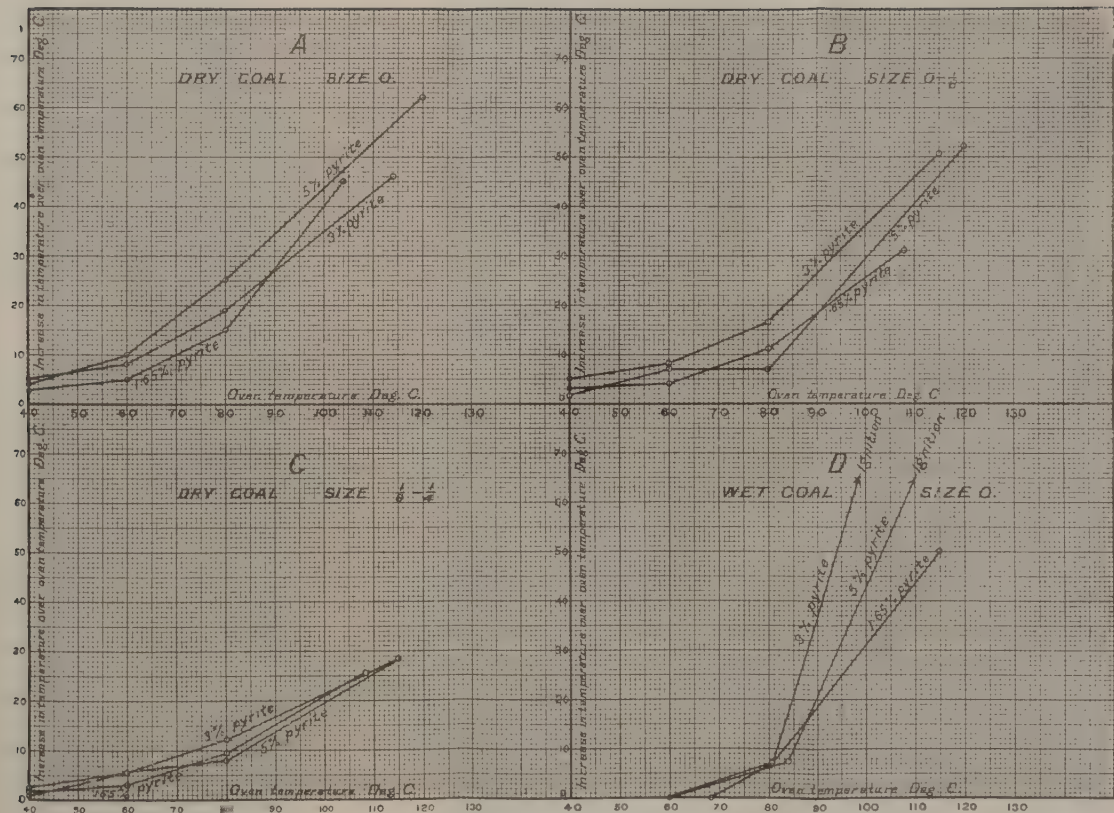


FIG. 3. Effect of pyrite on rate of oxidation.

(Redrawn from Parr and Krausman.)



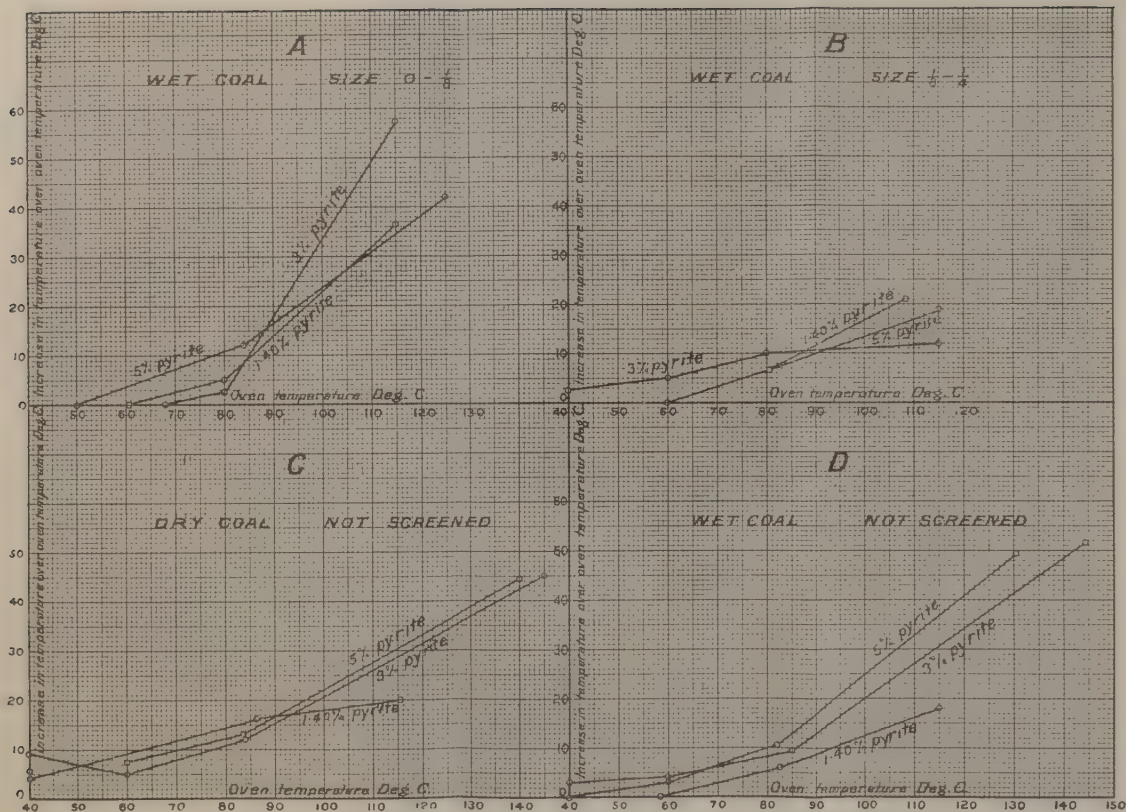
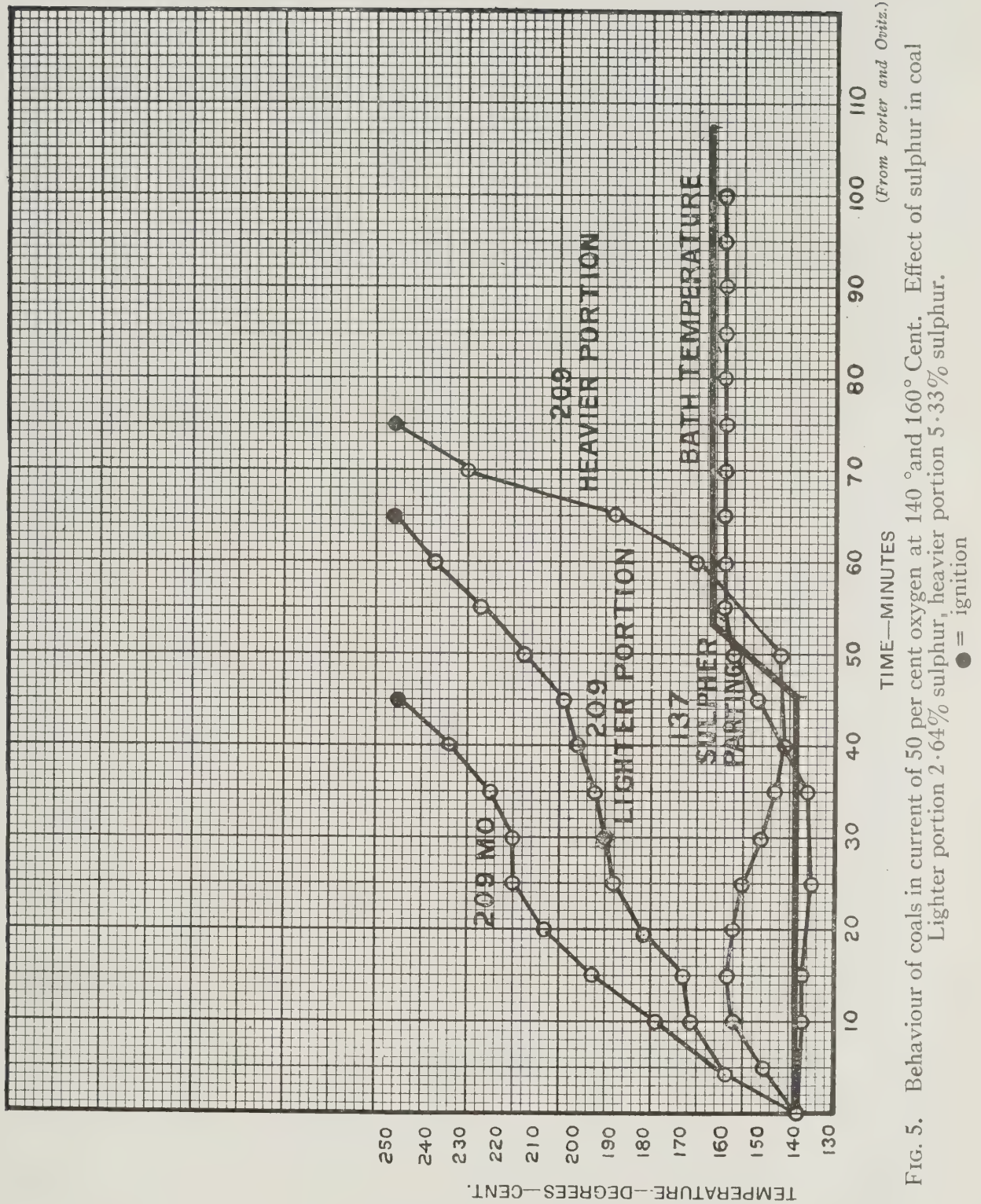


FIG. 4. Effect of pyrite on rate of oxidation.

(Redrawn from Parr and Kressman)





(From Porter and Ortiz.)

FIG. 5. Behaviour of coals in current of 50 per cent oxygen at 140 ° and 160 ° Cent. Effect of sulphur in coal  
 Lighter portion 2.64% sulphur, heavier portion 5.33% sulphur.

nation of the material showed that "some of it was pyrite". This statement implies that a large part of the "pyrites" in the coals they tested was really marcasite.

**Porter and Ovitz**<sup>1</sup> state that it was found that a particular coal containing 4-5% of pyrite gave a great deal of trouble; yet on analysis only 10% of the available sulphur had been affected. They made a laboratory test on a coal, taking it almost to a point of ignition, and on cooling and submitting a sample to analysis, the sulphur content was found to be almost unchanged: they point out, however, that the pyrites might possibly occur as pockets of fine particles, in which case, if neither too much nor too little moisture were present the temperature would rise to a considerable extent.

In connexion with this last observation of Porter and Ovitz the author has noticed the fact that coal piles are sometimes found to suffer from local heating in the immediate neighbourhood of lumps of pyrite or pyritic shale. This is not really a conclusive argument proving that the pyrites started the trouble, and it is very probable that the first heating was due chiefly to the organic matter of the coal, but we can see how the oxidation of the coal once having begun, would proceed with especial rapidity in the immediate vicinity of a mass of pyritic shale, a substance which every miner knows to be particularly prone to disintegrate.

Porter and Ovitz<sup>2</sup> quote Somermeier, *Journal American Chem. Soc.* 1904, p. 764 to the effect that

"Several samples of high sulphur coals, after standing one and a half years at ordinary temperature in the moist condition as received from the mines, showed a maximum of only 0.47% oxidized sulphur when kept in closed bottles, and 0.37% when kept in an open sack."

The exact amount of total sulphur in the samples is not stated, but it is estimated that one-tenth of it only was oxidized. They further state that a

"number of samples of weathered coal collected by them from out-door coal piles after six months to one year's storage, and in some cases after spontaneous heating had occurred in the coal, showed on analysis not over one-tenth of the total sulphur to be in the oxidized condition."

**Parr and Kressmann**,<sup>3</sup> whose experiments have been previously referred to on pages 37-40, calculated the heat rise which might be produced by the amount of pyrites which they found, at the close of an experiment, to have oxidized. The result showed a possible rise of about 74° C for dry bituminous coal. This looks imposing, but when account is taken of the fact that their coal was wet at the beginning of the experiment, it becomes clear that a much greater amount of heat must have been used up in the evaporation of moisture than would be necessary to raise dry coal to that temperature. The figure thus becomes more or less insignificant beside

<sup>1</sup> U. S. Bur. of Mines Tec. paper No. 16, 1912.

<sup>2</sup> 8th International Cong. Appl. Chem. Vol. X, pp. 251-267.

<sup>3</sup> Univ. Ill. Exp. Sta. Bull. 46, 1910.

the one which should be quoted for heat generated by oxidation of the coal substance itself.

Parr and Kressmann also experimented by adding pyrite to coal in varying quantities and then subjecting it to oxidation. They report that no matter how much pyrites was added to the coal the ratio of oxidized pyrites to total pyrites present remained constant. This would seem to be analagous to the matter of cyanide extraction of gold, in that a film of a constant thickness on the outside of each grain was probably attacked. The same size of pyrite was used throughout the experiments so that additional quantities would not affect the ratio of oxidized to unoxidized, or of oxidized to total pyrite present. It would have been very interesting had the pyrite for one experiment been so treated either by screening or by further crushing as to alter the ratio of exposed surface to quantity.

### Conclusions.

From the above review of the various and apparently contrary opinions held by the numerous experimenters who have studied the oxidation of pyrite in coal, it seems reasonable to conclude that the divergence of opinion is very largely due to differences in the coals studied, and that in an average bituminous coal the actual heat generated by oxidation of the pyrite is, in itself, not usually very important. Taken, however, in connexion with the fact that any small increase in temperature of the coal will greatly increase the rate of absorption of oxygen and consequent heat production, the heat produced by the weathering of pyrite may become a very important factor. Whether it will do so or not will depend on whether the coal under consideration can generate heat sufficiently fast by its absorption of, or chemical combination with oxygen, to raise its temperature to the danger point without assistance from the heat due to the oxidation of the pyrite. The effect of pyrite in liberating free sulphur and thus lowering the ignition point is unimportant since the point at which autogenous oxidation begins will have been passed before the ignition point of sulphur is reached.

The calorific value of a carbon hydrogen compound is so much greater than that of pyrites that a much smaller quantity of the former would yield any given amount of heat, and this fact taken in conjunction with the relative simplicity and accuracy of the chemical determination of sulphur makes it probable that heating has in many cases been ascribed to the alteration of the pyrite, when in reality it has been due to an oxidation of organic matter that has not been detected by the chemist.

There are, however, some coals in which the pyrite or marcasite is excessive in quantity or, like the "Barnsley softs" or the Williamson county, Illinois, "New Ohio," in which it is peculiarly susceptible to oxidation, and in such coals, it is probable that pyritic oxidation is an important, and perhaps the primary cause of heating. Such coals are, however, comparatively rare and, owing to their softness and excessive sulphur they

are of lower commercial value than normal coals. The problem of storing such coals for industrial use, although of great local interest is of relatively minor importance, but unfortunately, even when such soft shaly pyritic coals are worthless, they are bound to prove troublesome as they cause gob fires if left in the waste underground and yet are usually of little or no value if brought to the surface.

#### SIZE OF COAL.

Whether it be the pyrites in the coal which first oxidizes or the coal matter itself, it is clear that the action is largely superficial, or in other words, the rate of weathering in any coal is approximately proportional to the surface exposed to oxidation. This surface is of course inversely proportional to the diameter of the particles, or in other words a ton of coal in one-inch lumps has only half the surface of a ton of half-inch lump, or one one-hundredth the surface of  $\frac{1}{100}$ -inch lump, which may be taken roughly as the average size of coal dust, although really fine dust is of course much finer than this, and therefore has very much more surface.

Other things being equal, therefore, we may say that the rate of weathering increases directly with the reduction in size and is immensely more rapid with fine coal than coarse, but this is only true within limits, for in order that weathering may take place it is of course necessary for air to come into contact with the surface, and excessively finely divided coal packs so close that it is virtually impermeable to air and thus after the included air gives up its oxygen no more can gain access. Coal must, however, be exceedingly fine and suitably graded to be impermeable, and ordinarily we find that "fine" coal consists in a mixture of grains of all sizes from impalpable powder up. Such material is by no means impermeable and affords immense surface to oxidation as compared with coarse coal.

If we consider the effect of size alone on the rate of weathering we see from the above considerations that it acts in three ways:—

1. The rate of absorption of oxygen varies as the surface area of the coal, that is to say inversely as the diameter of the grains.
2. The rate of absorption will decrease as the supply of oxygen to the coal decreases, i.e. as the percentage of fines increases.
3. The circulation of air being better for lump coal more heat is lost by dissipation.

A pile of fine coal is more impervious to air than a pile of lump coal and hence fineness increases the absorption in two ways, but diminishes in another. The maximum of these three effects is attained in a mixture of very fine coal with coarse, but not very coarse, material, the exact sizes and proportions no doubt differing with coals of different character and composition.

The aim of every colliery is always to produce as large a proportion of lump coal as possible, not primarily because of anticipated difficulties due to weathering, but because lump coal burns better in ordinary use and

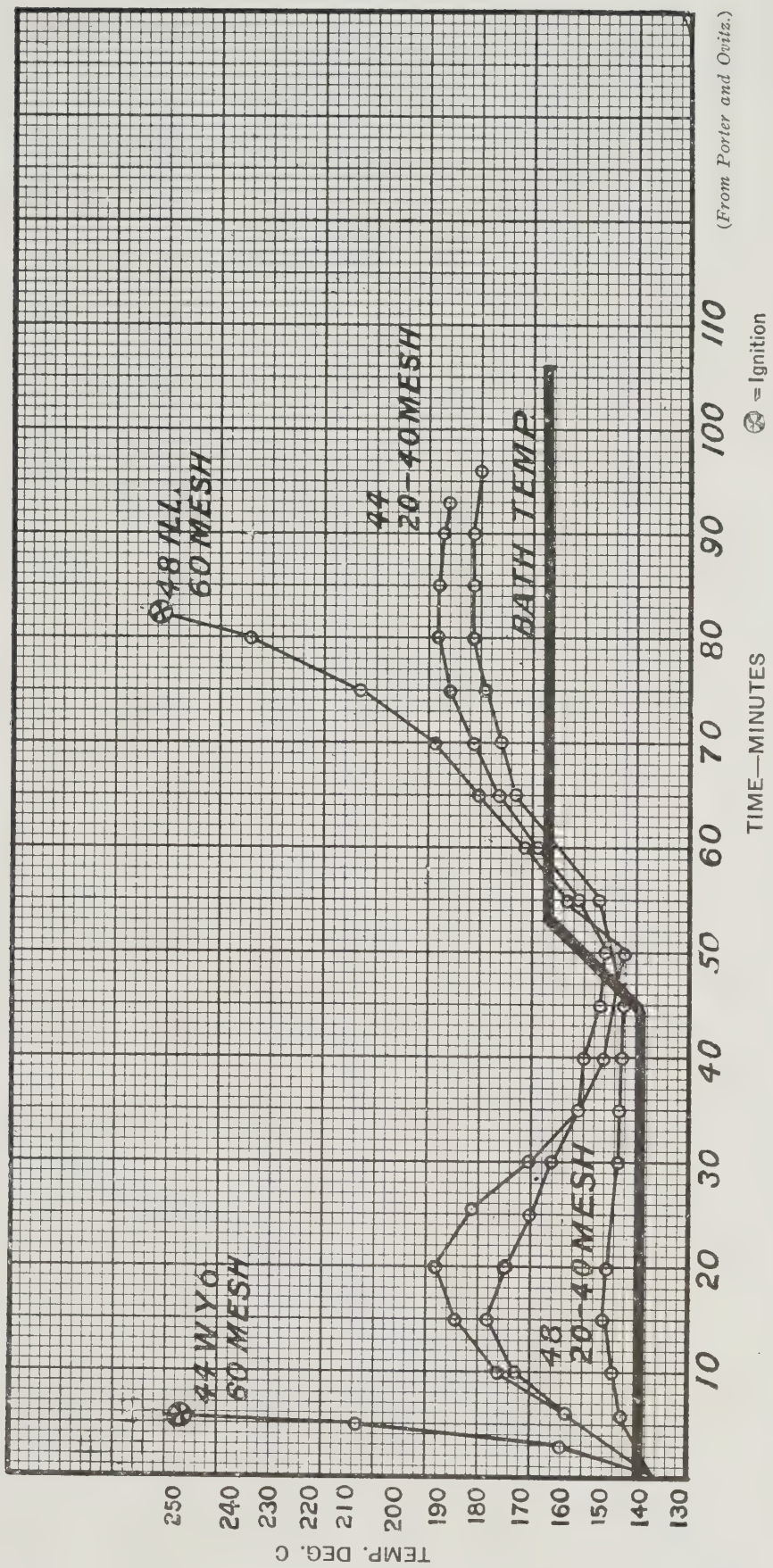


FIG. 6. Effect of size of coal on oxidation in current of 50 per cent oxygen at 140° and 160° C.

therefore, commands a better price; but the operations of mining unavoidably produce a considerable percentage of fines even from the hardest coals, and many otherwise very good coals are so friable that "slack" constitutes the chief product of the colliery.

In all cases the amount of fines increases as the coal is handled and shipped and thus by the time the coal reaches storage it contains a very large proportion of exceedingly fine material unless it is deliberately screened and the fines removed.<sup>1</sup>

In addition to the mechanical production of fine above referred to, further fines are produced as the coal weathers. Pyrite is largely responsible for this action as has already been pointed out,<sup>2</sup> the result being due in part to the actual bursting of the coal owing to the swelling of the pyrite on oxidation, and in part to the solvent action of the sulphuric acid produced on minerals such as calcite, etc., contained in the cleavage planes of the coal itself.

Pyrite is, however, not the only mineral constituent which breaks up coal by weathering, and Roth<sup>3</sup> names 30 other minerals which are liable to occur in coal, all affected by weathering, and some even soluble in water; these by dissolving or swelling tend to disintegrate the coal which contains them.

Fayol remarks that washed coal heats a little less than raw; this observation, which is not true of all coals, is probably due to the fact that washing removed a large proportion of the dust and fines from the coal, and as we see from Parr and Kressmann, the larger the coal the less it heats.

Porter and Ovitz draw attention to the fact that friability is a quality which should be noted for any coal, in that as size decreases, area and consequent oxidation increase.

Parr and Wheeler quote figures to show that the smaller the coal the greater is its loss in value per year.

Bement<sup>4</sup>, see Fig. 10, found that a good deal of disintegration took place in exposed storage; he recommends the storage of "egg" coal, as it shows the least tendency to disintegrate to smaller sizes, and it is free from marked spontaneous heating if undisturbed.

The experience of the Calumet and Hecla Mining Company may well be quoted here; they at one time stored all their coal in the form of "run-of-mine," and experienced much trouble from heating; upon changing their methods so that only oversize from a bar-screen was stored, and the under-size used as soon as possible, all trouble with heating of piles ceased.

The influence of size upon the action of two American coals exposed to oxygen is well shown in Fig. 6 taken from the work of Porter and Ovitz.<sup>5</sup>

<sup>1</sup> This was pointed out by De la Beche, Blackwell and Bunning, who were among the very early writers on the subject and all three held the view that fines were more dangerous than pyrite.

<sup>2</sup> See page 31 et seq.

<sup>3</sup> Chem. Geol. p. 69 et. seq.

<sup>4</sup> This writer's experiments on storing certain Illinois coals are interesting and valuable. See "The Loss in Coal due to storage." Am. Inst. Chem. Eng. Vol. III, 1910, p. 281.

Int. Cong. App. Chem., 1912. Vol. X, pp. 251-267.

When dealing with very small quantities of coal as in laboratory experiments, the effects of fines in reducing the loss of heat by radiation and in decreasing the supply of oxygen are negligible, and hence it is possible to get the direct effect of increased surface area by experiment. This has been done by Parr and Kressman<sup>1</sup>, and the results are shown in curves of which three sets are reproduced from their paper, (see Figs. 7, 8, and 9).

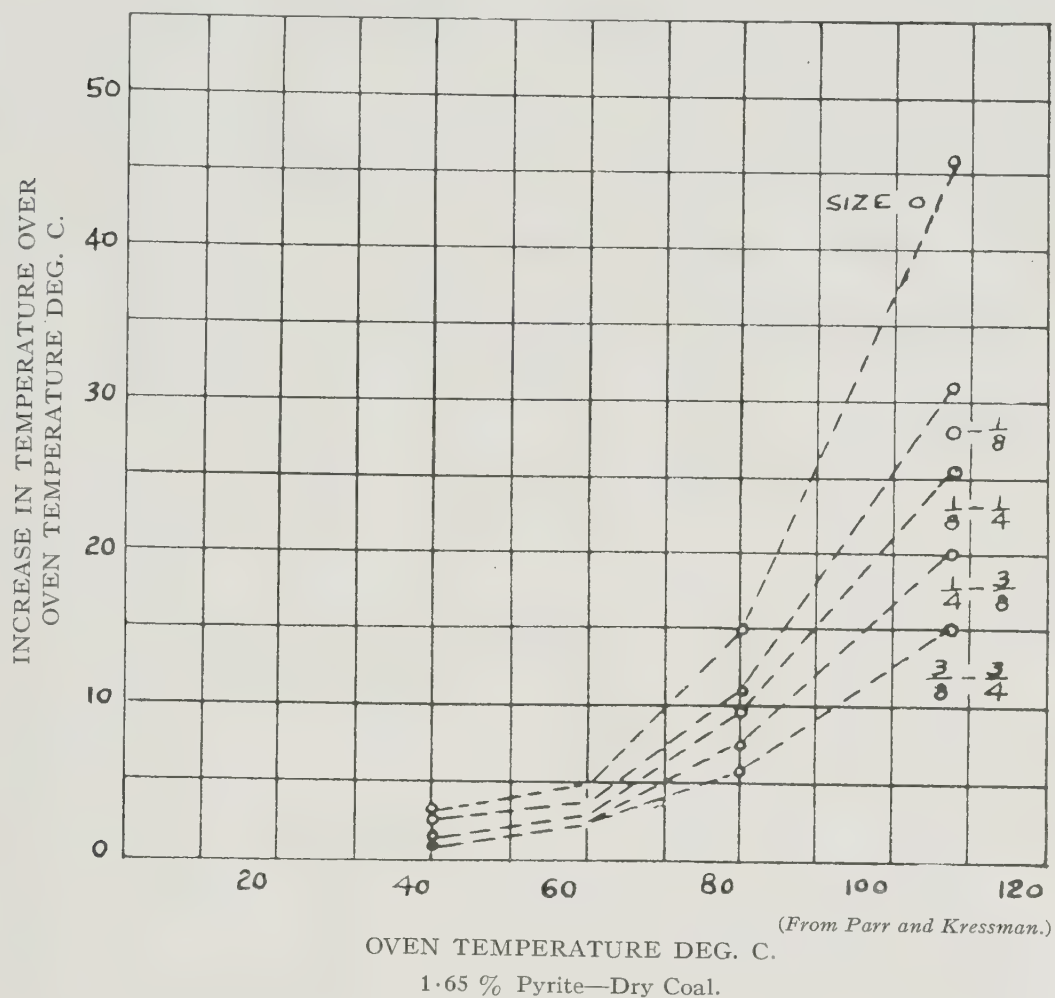


FIG. 7. Effect of size on rate of oxidation at elevated temperatures.

#### THE SIZE, SHAPE, ETC., OF THE STORAGE PILE.

When coal is kept in a storage pile for a considerable length of time it is a comparatively simple matter to study its condition by keeping a record of temperatures in a sufficient number of places in the pile. We can thus readily follow the variation in temperature of the mass, as all the reactions are exothermic.

Any heating of the interior of the pile, whether it be small or great, must be primarily due to oxidation, and the source of oxygen is the air which filled the voids in the broken coal during the piling, and other air which thereafter works its way into and through the interstices during the whole existence of the pile. Some of the heat evolved is lost by radiation and convection, but a considerable part of the loss is due to the cooling effect

<sup>1</sup> Bull. 46, Univ. of Ill. Exp. Sta., 1910.

of the interstitial circulation above referred to. It is thus clear that the physical condition of a storage pile, that is to say its bulk, porosity, etc., has a very important influence on its rate of heating. A thin or porous pile may oxidize rapidly, but it will be kept cool by radiation and excessive ventilation. A very high and compact pile will get too little air to support any serious oxidation in the interior and its deeper parts will, therefore,

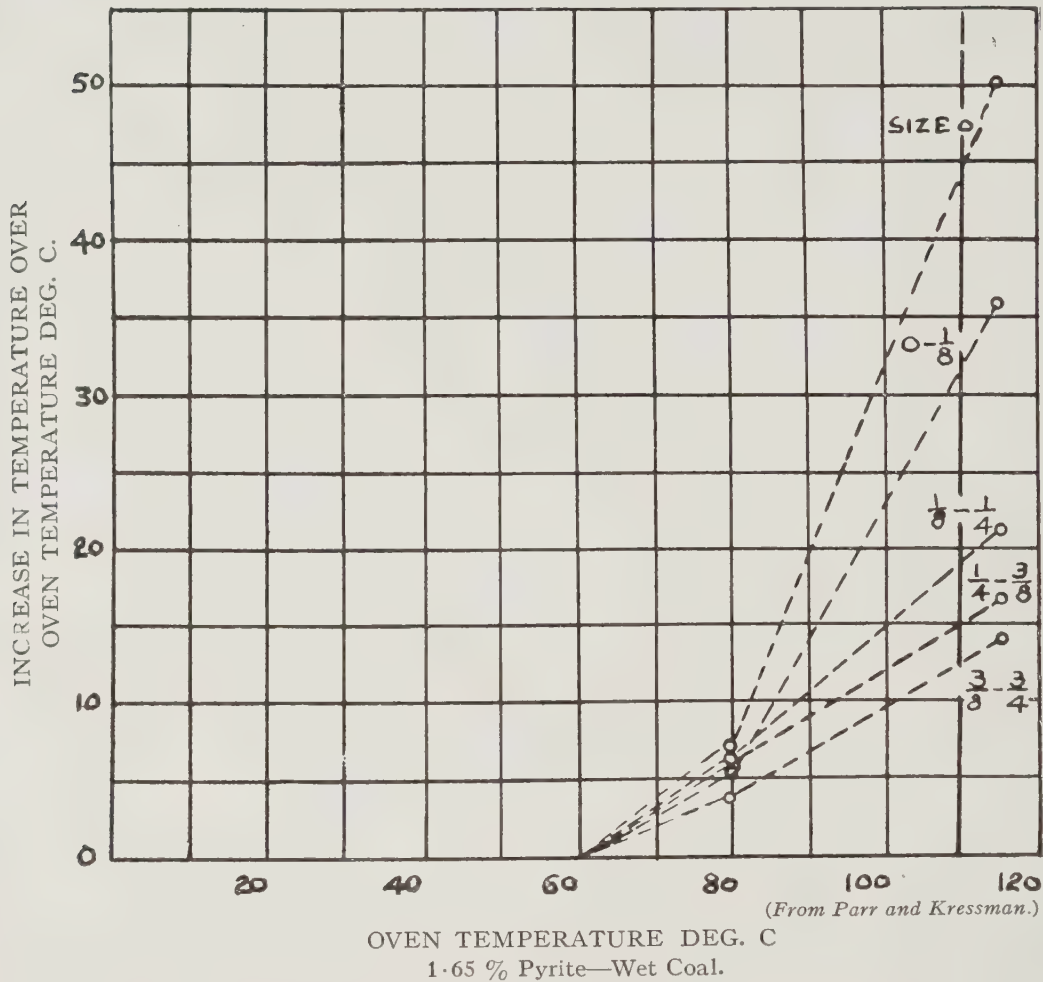


FIG. 8. Effect of size on rate of oxidation at elevated temperatures.

heat very little. A pile of intermediate porosity or a particular zone in a large pile will get enough air to cause heating and not enough to carry the heat away and will thus give a maximum of trouble.

This matter of porosity is of greater importance than might at first be imagined as the interstitial spaces in a pile of broken mineral range from 15 per cent to nearly 50 per cent of the total bulk, but in addition to this the initial temperature of piling also has a considerable effect. Oxidation proceeds, other things being equal, more rapidly as the temperature rises, and the rate of ventilation also increases both for evil and good as the coal gets hotter and the difference between the internal and the atmospheric temperature rises.

The inseparable way in which the phenomena of this subject are bound together is further shown when we consider that coal ordinarily contains pyrites or marcasite, and these constituents under the influence of moisture

cause disintegration which, while increasing the oxidizing surfaces, reduces the interstitial spaces in the heap; while upon surface exposed and circulation of air depend the rate of oxidation and consequent heating, and also the subsequent cooling of the pile upon excess of air to the mass. It is clear therefore that a great deal may be learned by observing the behaviour of storage piles, if an attempt is made at the same time to obtain full information as

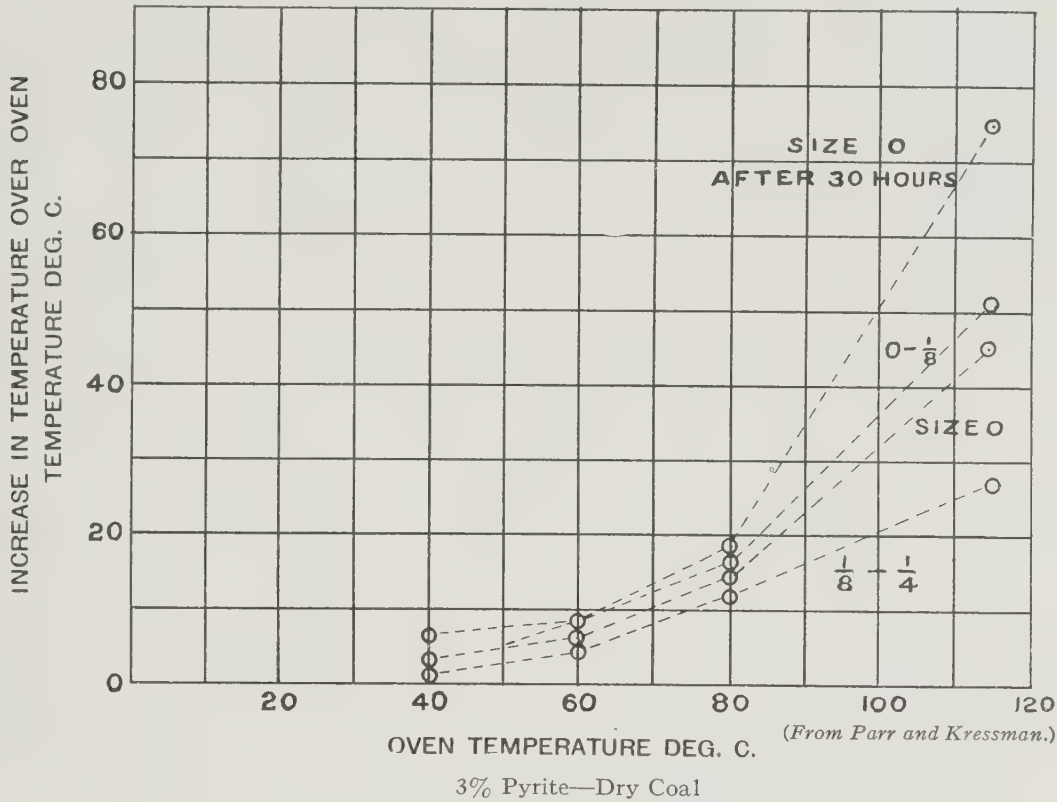


FIG. 9. Effect of size on rate of oxidation at elevated temperatures.

to all of the various factors which enter into the matter; but as a full consideration of these factors would open up the whole subject of weathering we shall content ourselves for the present with noting a few observations, particularly concerned with the size and temperature of storage piles.

**Fayol** experimented with respect to the limit of depth by constructing a pile much higher at one end than the other, and placed thermometers at intervals in the mass as shown in Fig. 11, and it will be noted that heating took place in the deepest part of the pile about a foot from the ground. Fayol concludes that Commentry coal will heat dangerously if stacked in heaps exceeding two metres in depth.

Another of Fayol's experiments was with a pile in which he regulated the rise and fall of temperature by opening and closing holes in a tight fitting cover. This gave a very interesting demonstration of the effect of air supply. (Fig. 12).

**Porter and Ovitz** experimented in the laboratory on the rate of heating under varying rates of air supply and set forth their observations in a curve which is reproduced at page 54 (Fig. 13). They say that "The ideal conditions for heating are supplied by a large pile of run of mine coal con-

taining a large percentage of dust, piled in such a manner that the air may enter." Presumably the large lumps of coal in this case would serve merely to protect spaces large enough for air to attack the fine dust.

**Porter and Brunton** studying storage piles of Sydney coal in Montreal (see p. 159), obtained apparently contrary results from those of Fayol referred to above, but the explanation is perfectly simple. In Fayol's

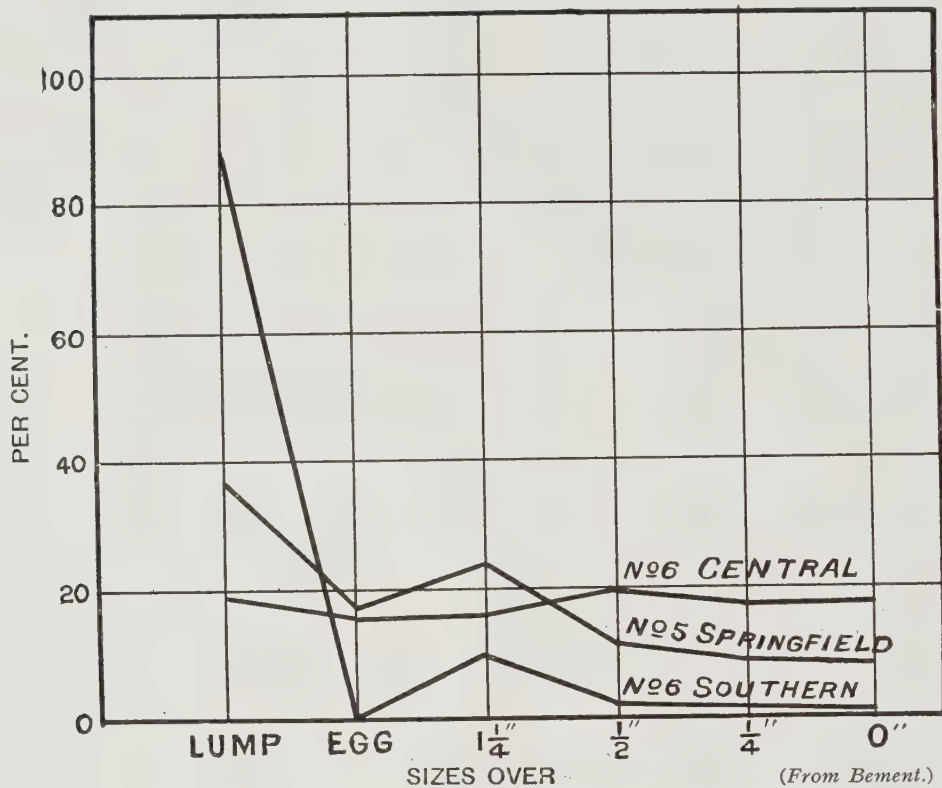


FIG. 10. Tendency of coal to disintegrate. Original samples 100 per cent lump, which in one year's outdoor storage broke down to sizes as shown.

experiments the pile was a small one provided with an impervious cover and when the air supply was totally shut off oxidation had to stop and the pile lost heat by radiation. In the case of the very large pile observed by Porter and Brunton there was no impervious cover, and on the other hand the pile in its normal state had ventilation holes 16 inches apart throughout its mass. These holes permitted access of so much air that the pile was kept cool in spite of its slow oxidation, but when the holes were closed this cooling effect ceased, and the pile heated somewhat rapidly. As a matter of fact the Porter and Brunton pile when closed was substantially in the same condition as the Fayol pile when open, and under this condition both piles heated. The two sets of observation therefore confirm one another.

Porter and Brunton also found that although a pile may be covered with snow at the surface yet three feet below the surface of the coal the temperature may be quite high, thus incidentally confirming, although in a negative way, the observations of the New South Wales Commission referred to on p. 55.

Porter and de Hart working with experimental piles at Glace Bay, N.S, found that under the conditions of their trials fresh coal quickly piled heated

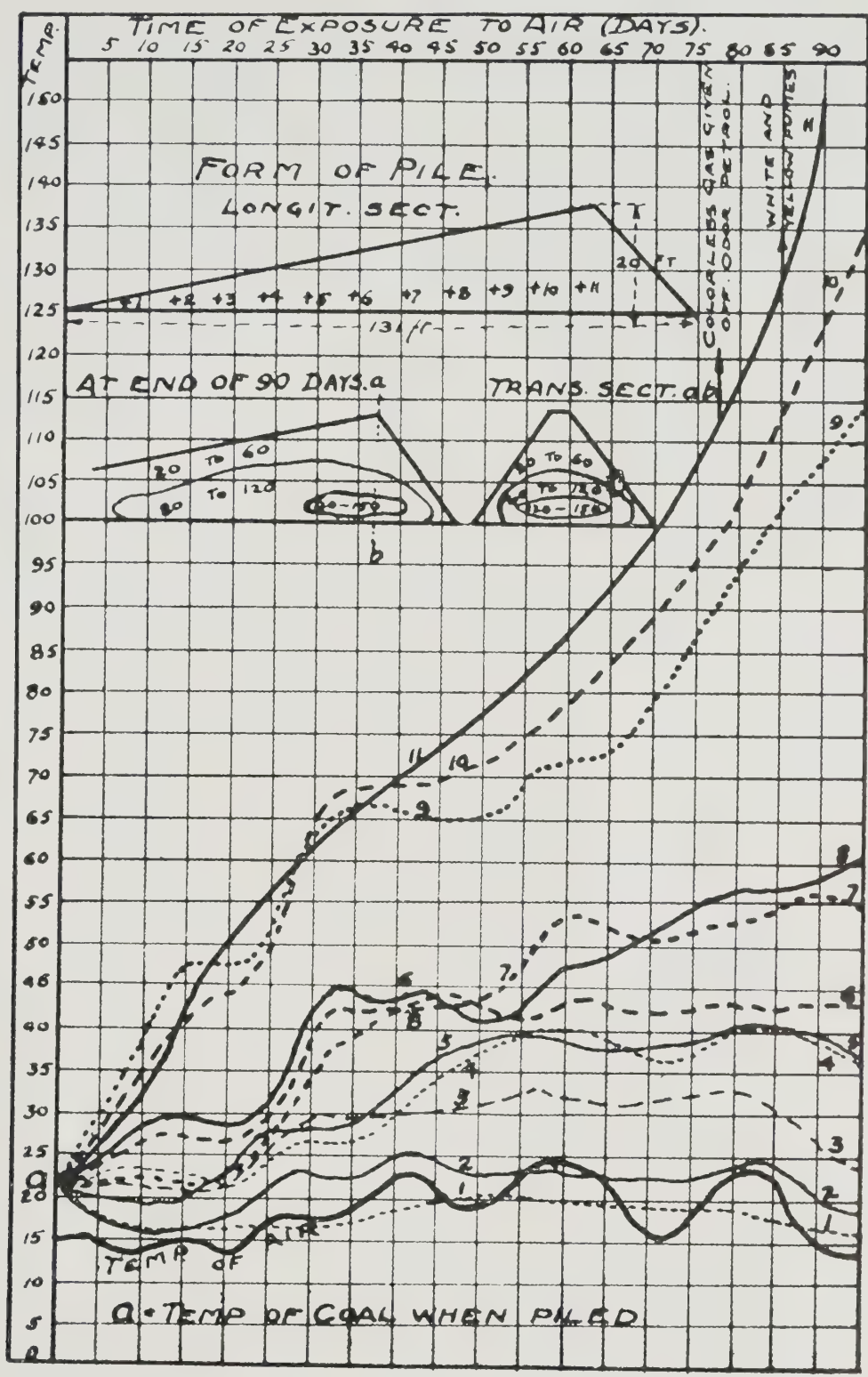
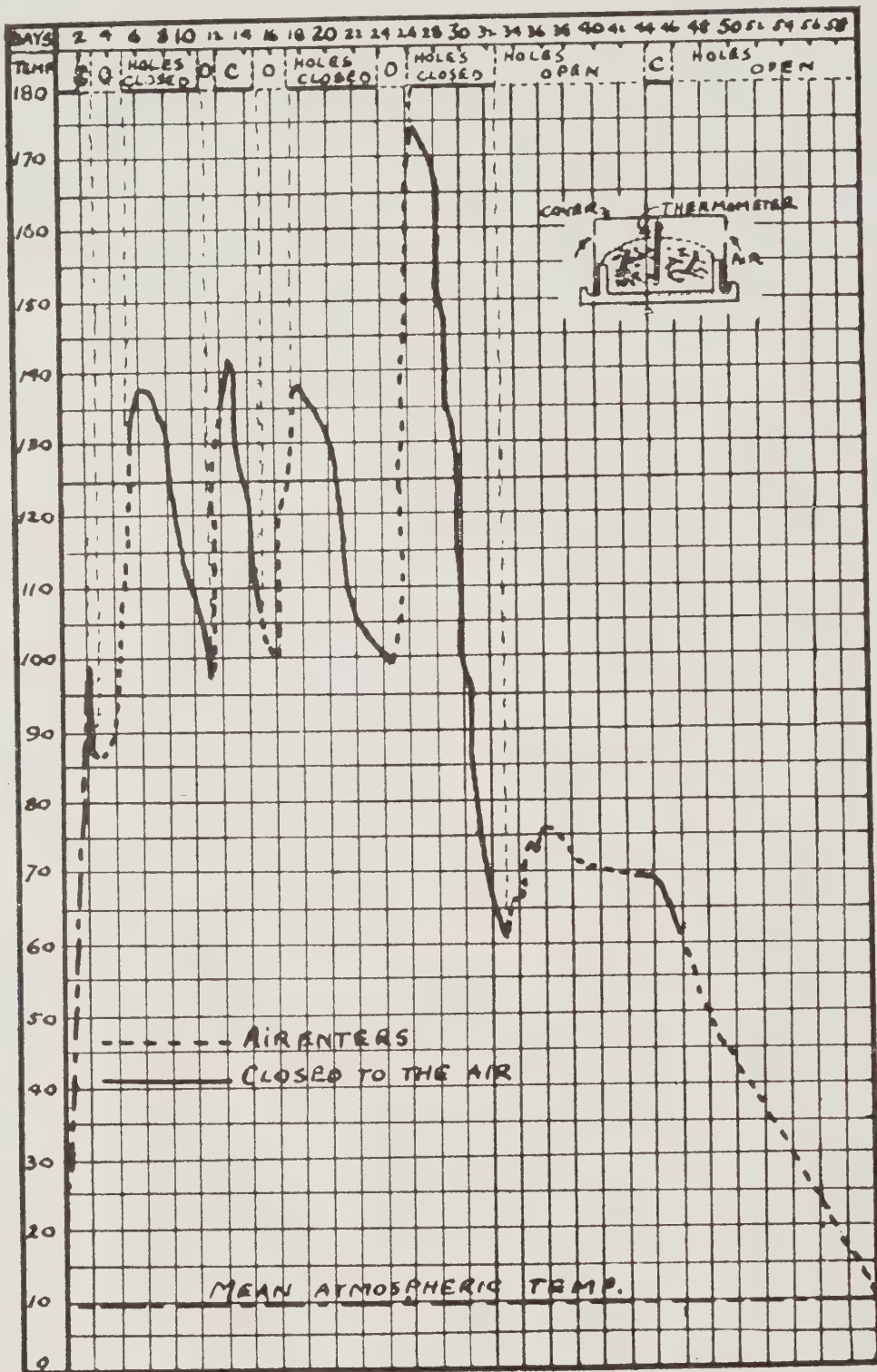


FIG. 11. Form and temperature of coal piles.

more rapidly than the same coal slowly piled, or than stale coal repiled. Their results are given in some detail on pages 154-159.

## THE INITIAL TEMPERATURE OF STORAGE.

Fayol, who first dealt scientifically with the subject of the initial temperature of a storage pile, found that Commentry slack if raised to a tem-



(Redrawn from Fayol.)

FIG. 12. Form and temperature of coal piles.

perature of between  $60^{\circ}$  and  $70^{\circ}$ , would continue to generate heat of itself, but that if the temperature of a heap did not rise to  $60^{\circ}$  then it would gradually cool off again. It may be noted that this coal is peculiarly susceptible

to atmospheric influences, and has in fact a lower point of so called "autogenous oxidation" than almost any other important coal with which the writer is familiar.

Fayol also made a series of experiments exposing small lots of various other coals to elevated temperatures in ovens. These experiments are also referred to in another connexion on pages 26 and 108-9. Some of the results obtained are shown in the following table which demonstrates the effect of the external heating on the ignition point. The coal in each case was contained in a box 12 centimetres square by 3 cms high. The sign + indicates that the coal caught fire, and — indicates no ignition. The small figures show the time which elapsed before ignition took place. From these experiments Fayol concluded that the temperature at which coal is piled will have a large effect on its rate of heating and its ultimate temperature. Any external heat as from the sun or from steam pipes would of course have a similar influence.

TABLE IX.

**Time Required to Ignite Coals Heated to Different Temperatures.**

Coal	Temperatures of stoves			
	100°	150°	200°	400°
	Impalpable Powder			
Anthracite (Marais).....	—	—	—	7 mins. +
Bituminous coal (Trevil).....	—	2h. 20 mins. +	1h. 10 mins. +	5 mins. +
Gas coal (Commentry).....	5h. +	2h. 50 mins. +	50 mins. +	1 min. +
Lignite (Vosges).....	7h. 50 mins. +	1h. 20 mins. +	40 mins. +	5 secs. +
	Dust through $\frac{1}{2}$ mm. screen.			
Anthracite (Marais).....		—	—	35 mins. +
Bituminous coal (Trevil).....		—	—	25 mins. +
Gas coal (Commentry).....		6h +	1h. 30 mins. +	10 mins. +
Lignite (Dordogne).....		5h. 20 mins. +	1h. 40 mins. +	1 min. +
	10 mm. grains			
Anthracite (Marais).....		—	—	50 mins. +
Bituminous coal (Trevil).....		—	—	20 mins. +
Gas coal (Commentry).....		—	—	20 mins. +
Lignite (Dordogne).....		—	—	3 mins. +

**Parr and Wheeler** give an example in which coal kept in an oven at  $110^{\circ}\text{C}$ . has risen to  $200^{\circ}\text{C}$ . of itself.

**Parr and Kressmann** whose experiments with various sizes of coal stored at elevated temperatures have been described at some length on pages 37-40 and 42-43, give  $200^{\circ}\text{C}$ . to  $275^{\circ}\text{C}$ . as the temperature of auto-genous oxidation in air, while they say that firing or actual kindling does not take place until a temperature beyond  $350^{\circ}\text{C}$ . is attained.

Their estimate is no doubt correct for the coal with which they experimented, but their figure is much too high for general acceptance, and unfortunately many of the most important coals of eastern Canada and the United States cannot rise to nearly so high a temperature without risk, and in general there is grave danger when a coal pile of its own accord heats above  $100^{\circ}\text{C}$  in temperature, as such a temperature indicates that the heat given off by the coal is more than counterbalancing the cooling due both to radiation and the evaporation of the moisture present, and as soon as all the moisture has been driven off a rapid rise in temperature is liable to ensue.

That temperature has very great influence upon oxidation, is shown in a curve drawn by **Porter and Ovitz**, (Fig. 13A) which approximates to the form of a parabola. The temperature at which autogenous oxidation begins appears to vary with different coals, as might be expected.

### General Discussion and Conclusions.

The term "autogenous oxidation" has been so widely used that it is retained in the present volume, but the word autogenous is not always correctly employed, and here as elsewhere it is liable to give rise to misapprehension. There is undoubtedly for each particular case some particular temperature below which oxidation will generate heat no more rapidly than radiation and convection can dissipate it; and coal stored below this temperature will not rise above this critical point, and will, therefore, be safe; whereas the same coal stored at a higher temperature, or heated by any means to such a temperature, will have its rate of oxidation accelerated, and will thus generate heat more rapidly than it dissipates it, and, therefore, grow hotter and hotter until it ignites. This critical temperature is, however, dependent not merely on the particular coal used, but on the size and shape of the pile, the size of the fragments of coal itself, the degree of moisture, and to a certain extent on the external temperature, the character of ground under the coal pile, etc., etc. The changes in the critical temperature due to variations in these numerous factors are so great that any statement of the temperature of autogenous oxidation of a coal is useless and often mischievous unless accompanied by a statement of the determining conditions. It is, however, quite possible for persons experienced in the storage of particular coals to arrive experimentally at the approximate critical temperature below which their coal in their standard storage pile may be permitted to heat without anxiety to those in charge; while if the

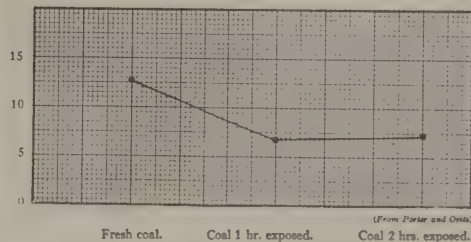
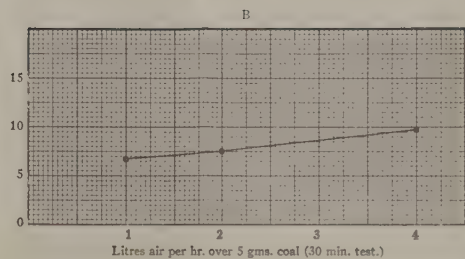
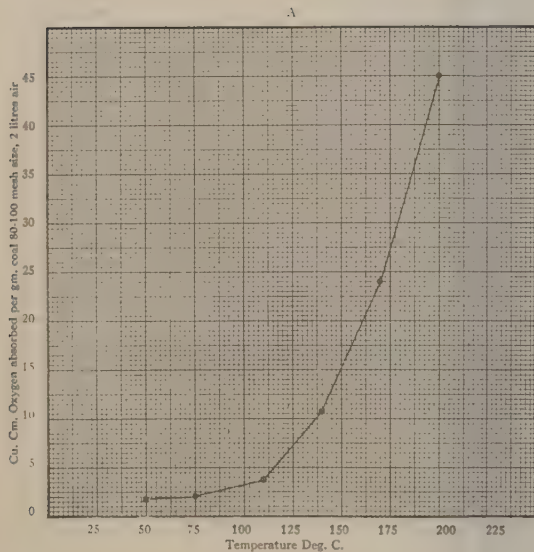


FIG. 13 A—Effect of temperature on rate of oxidation of dry coal.  
 B—Effect of rate of air supply on rate of oxidation of dry coal.  
 C—Effect of previous exposure on rate of oxidation of 200-mesh coal at 140° C.

Cu. Cm. absorbed per gm. at 140° C.



heat in any spot rises above this temperature the coal requires prompt ventilation, careful watching, and possibly digging out.

From what has been said above it is obvious that the initial temperature of storage is of very great practical importance. Attention was directed to the matter in 1898 by the New South Wales Commission which recommended strongly that when coal was put into storage in any shape or form, the handling should be carried out as much as possible during the coolest part of the day. The commission was considering the case of loading ships in a subtropical climate, and its advice appears very necessary in that if the coal is being loaded while the sun is shining it becomes greatly heated and these hot layers get covered over and so retain their heat as the superincumbent coal is a poor conductor. As a matter of fact the Commission's advice is good even for temperate climates, and piles made in summer are often quite hot to start with and liable to give trouble. Of course the converse is also true and piles made in winter rarely give trouble; in fact it is said that ice and snow are sometimes found as late as midsummer in coal piles made at Glace Bay in midwinter.

Every precaution should also be taken to ensure that coal after being stored is not heated even locally from some external source. Coal piled near boilers, and particularly over or around hot pipes or flues is quite liable to develop violent spontaneous combustion. The action of the sun on a finished pile is on the other hand not likely to do harm as it is superficial and the heat gained in the day is usually lost in the night.

Porter and Ovitz cite a case in which a pile of cinders was observed to take fire due to the influence of heat radiated to them from a furnace. The cinders contained in one case 33%, and in another 40% of carbon.



## CHAPTER IV.

## THE OXIDATION OF COAL.

In the preceding discussion an attempt has been made to study each of the different factors in the weathering of coal by itself, or as nearly by itself as is possible, in order that the part played by each of these factors should be understood. It is, however, difficult and often impossible to portion out the results correctly among the several causes, and in the three next chapters we shall deal with the matter of weathering in a broader way, first discussing oxidation of the coal as a whole, and then the practical problem of how best to prevent or minimize the weathering of stored coal.

We have already seen that all coals except the hardest anthracite absorb more or less oxygen on exposure to the air. This action may be considered under three heads: occlusion, oxidation proper at low temperatures, and oxidation at elevated temperatures.

In occlusion the action is virtually the concentration of oxygen on the surface of the carbonaceous matter; this surface being enormously large in the case of powdered or porous material. No actual chemical combination takes place, but a considerable amount of oxygen is extracted from the air and retained by the coal, and a certain amount of heat is developed. The same phenomenon is even more markedly shown by charcoal which if freshly burned will on exposure occlude eighteen<sup>1</sup> times its bulk of oxygen; in fact some kinds of charcoal occlude far more than this, and animal charcoal takes up so much oxygen that it is liable to be so heated that actual oxidation and combustion take place.

Occlusion, which is a property of many solids with relation to many gases, is theoretically quite distinct from reaction, such as oxidation. The gas is merely condensed on the surface of the solid in a film of almost infinite thinness and no chemical combination between the two need take place, but when the gas is oxygen and the solid is a readily oxidized material such as coal, the condensation of oxygen on the surface and the consequent rise in temperature naturally lead to oxidation, and in practice it is virtually impossible to distinguish sharply between the two. Similarly, although oxidation begins at low temperatures it develops heat often more rapidly than it can be dissipated, and in such cases the temperature of the mass rises at an ever increasing rate until ignition takes place and actual combustion occurs.

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<sup>1</sup> Hunter, *Phil. Mag.* (4) Vol. 25, 1863, p. 364.  
Dewar, *Ann. Chim. Phys.* (8) Vol. III, 1904, pp. 5-12.

## OCCLUSION AND OXIDATION AT ORDINARY TEMPERATURES.

As has just been explained it is very difficult in practice to distinguish between the occlusion of oxygen by coal and the earlier stages of actual oxidation. The two will, therefore, be considered together, although the cases in which occlusion is probably important will be dealt with first.

**Percy**<sup>1</sup> states that one part of the oxygen absorbed combines with part of the carbon and hydrogen of the coal forming carbon dioxide and water vapour; while another portion enters into an unknown state of combination with the organic substance of the coal, and the remainder is consumed in oxidizing the iron pyrites invariably present in the coal.

**Lewes**<sup>2</sup> is of opinion that the absorption of oxygen is, at any rate at first, purely mechanical. He states that the absorption is at first very rapid, but the rate, which is very much influenced by temperature, decreases. This mechanical absorption causes a rise in temperature, which tends to increase the rate of the action which is going on, but which is rarely sufficient to bring about spontaneous combustion. Lewes states that air dried coal absorbs oxygen more quickly than wet coal. The gas which has been thus mechanically absorbed becomes chemically very active and soon commences to combine with the carbon and hydrogen of the bituminous portion of the coal converting them into carbon dioxide and water vapour.

**Fayol**<sup>3</sup> is of opinion that the oxygen combines chemically with the coal. His arguments in favour of this hypothesis are:—

1. That the absorption of oxygen by coal is helped by an increase of temperature whereas the occlusion of gas by charcoal is impeded by rise of temperature.

2. That charcoal returns to its original state when gas, which has been occluded, is driven off by heating, but that coal is permanently altered by the absorption of oxygen.

3. That if the absorption were mechanical it would be equal all through a lump which had been exposed to hot air, but such a lump of coal shows an alteration which is entirely superficial in character.

4. The analogy which exists between coals naturally rich in oxygen and coals which have absorbed it.

**Cox**<sup>4</sup> found that at first more oxygen was absorbed by coal than would account for the carbon dioxide evolved, but that after some months' exposure the evolution of carbon dioxide was in excess of the quantity of oxygen absorbed. In such cases part of the oxygen no doubt is occluded or condensed on the surface of the coal at the start, and while in this condition, it is better able to attack the coal-substance.

**Stansfield**<sup>5</sup> in a short discussion of the subject, remarks to the following effect upon the heat evolved by occlusion or condensation of gases, and the part that this might play in the heating of coal.

<sup>1</sup> Metallurgy-Fuel 1875, pp. 289-298.

<sup>2</sup> T. I. Naval Architects. Vol. 31, 1890, pp. 204-228.

<sup>3</sup> Études sur l'altération de la houille exposée à l'air. M. Fayol, 1879.

<sup>4</sup> Internat. Cong., Appl. Chem. Vol. X, 1912, pp. 109-28.

<sup>5</sup> The Coals of Canada. Vol. VI, 1912, p. 95-120.

There can be no doubt that coal absorbs oxygen. This absorption may be mechanical, or chemical, or both. The heat evolved would be very different if the absorption were chemical from what it would be if it were mechanical, but if mechanical absorption merely preceded chemical combination the total heat evolved would be the same as if there were only chemical combination. The above statements are true whether the oxygen combines with carbon, sulphur, or any other constituent of the coal.

When a gas is absorbed by charcoal, it is rendered very chemically active, though not sufficiently so to combine, to any appreciable extent, with the pure carbon of the charcoal. If oxygen were absorbed by coal in a similar manner there would be every reason to believe that it was thereby rendered very chemically active. The experiments of Richters show that some of the carbonaceous matter of coal is more easily oxidized than the rest. It is quite conceivable that the absorbed oxygen would combine with the relatively easily oxidized compounds of carbon, oxygen, and hydrogen present in the coal. These reactions would give out heat and thereby increase the chemical activity of the oxygen and might be conceived as heating the mass sufficiently to allow the oxygen to combine with the more difficultly oxidizable carbon. This chemical action, in which only oxygen which has already been mechanically absorbed is involved, would not prevent the mechanical absorption from being proportional to the partial pressure of the oxygen.

There is one other theory as regards the absorption of oxygen: namely, that suggested by **Haldane** and **Meachem** to the effect that the oxygen absorbed is all used up in oxidizing the pyrite present in the coal. This theory, however, is contrary to the fact that the absorption of oxygen by coal is not proportional to the amount of pyrite present, but as has already been stated in another chapter it is probable that pyritic oxidation does play some part in nearly all cases of coal weathering.

In 1870, **Richters**<sup>1</sup> showed by rough calculations based on experiments, that coal frequently absorbed so much oxygen that if it all combined with the carbonaceous matter of the coal, and the resultant heat were not dissipated, the temperature of the coal might be raised above the ignition point. He first made experiments to find the amount of oxygen absorbed by 20 grammes of different coals in twelve days. The coals used were dried in the air, but were not heated to drive off hygroscopic water. The results are as follows:—

Sample.....	1	2	3	4	5
Moisture.....	5·15%	5·20%	5·25%	2·54%	3·10%
Oxygen absorbed.....	45·8c.c.	50·1c.c.	50·0c.c.	18·2c.c.	39·9c.c.

The calculation proceeds as follows:—

“Since 20 grammes of air free coal occupy a volume of about 15 cc. it follows that samples 1, 2 and 3 absorbed, in twelve days, more than three times their own volume of oxygen.

<sup>1</sup> This extended quotation from Richters is offered because neither the original papers in *Dinglers Polytechnisches Journal* nor the translations in the Report of the N. S. W. Royal Commissions are to be found in any but the largest libraries. His work is exceedingly valuable and interesting and is more thorough and trustworthy than that of any other of the early students of the subject with the one exception of Fayol.

Sample 5 absorbed two and half times its volume and sample 4 over one and a quarter times its volume."

"According to Sassure one volume of boxwood charcoal absorbs 9.25 volumes of oxygen. Since the weight of a cubic centimetre of the charcoal examined by Sassure was 0.6 grammes we see that 20 grammes would absorb 308 cc. of oxygen or about six times more than was absorbed by coal (samples 2 and 3) in twelve days. Now it is known that this absorption of oxygen is sufficient to raise the temperature of the charcoal to its firing point, which, according to Viollette, lies between 400° and 600° C, say 500° C as a mean.

Let us assume that the quantity of oxygen absorbed is diminished in the ratio of one to one-sixth, the heat which is liberated will also be diminished in the same ratio. Assuming that the same amount of heat is liberated by coal as by charcoal when the quantity of oxygen absorbed is the same in both cases, and also that the mean firing temperature of charcoal is 500° C it appears that coal, (samples 2 and 3) would, during twelve days, rise in temperature to an extent represented by  $\frac{500}{6}$ , that is through 83°. This, of course, is on the assumption that the specific heat of the coal is the same as that of the charcoal, which is only approximately the case, and that no heat is lost in any way". In practice some of the heat generated is lost by radiation, but Richters believes that this is more than compensated for by the increased absorption which goes on as the temperature rises. He says, "In a former communication I have shown that three different kinds of coal which were exposed to a temperature of about 70°—80° C. lost 3.6 per cent of their heating power."

"Let us calculate theoretically the quantity of heat liberated by the coal during fourteen days oxidation while it was losing the 3.6 per cent of its heating power."

1.76% carbon oxidized to carbon dioxide yield.....	140 calories.
0.16% hydrogen oxidised to water yield.....	55 calories.
2.12% oxygen absorbed forming water remaining in the coal.....	91 calories.
Total.....	286 calories.

"This table shows that for 1 lb. of coal 286 units of heat are liberated. If this heat were solely employed in raising the temperature of the coal, that temperature would amount to 1,100° C, or, more correctly, the coal would quickly be raised above its firing temperature, and would then burst into flame. It appears, therefore, that the heat, which is liberated is quite sufficient to raise coal to its firing temperature".

"Whether this temperature will be reached or not in any specific case depends (1) upon whether the coal can obtain a sufficiency of oxygen and (2) whether the heat developed at such temperature can or cannot pass off as quickly as it is generated."

Richters' calculation is based on a number of assumptions. Most of them are no doubt substantially true, but a considerable part of the heat generated always necessarily passes off by radiation and convection and as a matter of fact few if any coals catch fire spontaneously unless exposed to the air for much longer periods,<sup>1</sup> except when they have been previously heated.

Richters' observations have been confirmed by Parr and Francis<sup>2</sup>, who were able to experimentally note in coal indications of a type of combustion or heat generation accompanied by evolution of gases at a temperature far below the ignition point.

**Taffanel** says that oxidation has two main forms, absorption of oxygen by the coal, and removal of carbon as carbon dioxide; there is probably a third form in the removal of hydrogen as water, but this has not been deter-

<sup>1</sup> Journ. N. of Eng. Inst. Min. & Mech. Eng. Vol. 35, 1876, p. 107.

<sup>2</sup> Bul. Univ. Ill. Eng. Expt. Sta. No. 24, 1908.

mined with any degree of accuracy, although determinations of hydrogen have shown sensible variations in the proportions of this substance.

The rate of fixation of oxygen varies with the nature of the coal, and it appears, in general, greater for coals rich in volatile matter than for those poor in it. The rate varies with time, being comparatively rapid at the beginning of exposure, but slow towards the end.

Richters himself at a later date and several other experimenters have confirmed and extended the above observations, and certain of their observations may be noted here.

**Richters**<sup>1</sup> experimented with two forms of apparatus. One consisted of a glass tube open at one end and capable of being closed at the other by means of a tap. The other was an apparatus devised by Dietrich for gas analysis, and more particularly for the determination of carbon dioxide, modified in that the lead condensing worm was replaced by a glass tube. A weighed quantity of coal was introduced into the glass tube of the first apparatus and packed tight with a small asbestos stopper. The open end of the tube was dipped below mercury and the tap at the upper end allowed equilibrium to be established between the external and internal pressure. After standing for one hour during which the temperature of the room had been kept constant, the tap was closed and the volume, temperature and height of the barometer were noted. When using the Dietrich apparatus the flask intended for an evolution of gas was employed as a receptacle for the coal.

The first experiment was made with the Dietrich apparatus. Fifty grammes of powdered coal, from the Jacob level of the Theresien shaft were used, which had been lying in a loosely stopped bottle exposed to the air in the laboratory for two months. Readings were taken every twelve hours and reduced to normal temperatures and pressure. In 168 hours, 16 cubic centimetres of air were absorbed. To determine whether the absorbed gas was oxygen or not, the oxygen left after the experiment was absorbed by an alkaline solution of pyrogallol. Taking air as containing 20·8% of oxygen by volume, there were originally present 40·5 cubic centimetres of oxygen. Thus if all the gas absorbed by the coal was oxygen, there should have been 24·5 cubic centimetres of oxygen left, but only 23·1 cubic centimetres were absorbed by the pyrogallol solution. Richters did not claim any great degree of accuracy for this experiment; but it clearly showed that oxygen is absorbed by coal.

The second experiment was made in the calibrated glass tube with 20 grammes of coal. After nine days 6·6 cubic centimetres of oxygen, i. e., 95% of that originally present, had been absorbed and after this there was no more absorption. Powdered coal was used from the Robert level of the Theresien shaft. The sample was dried in a desiccator until its weight became constant and then immediately removed to the slightly warm tube through which a gentle stream of dried air was passed until the tube became cold.

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<sup>1</sup> Report of N. S. W. Commission on Ships carrying Coal. 1898.

A third experiment was made with the same apparatus and 20 grammes of coal powder from the Carl level of the Theresien shaft. The air was saturated with moisture during the whole experiment. In 10 days 7·2 cubic centimetres of oxygen were absorbed. The air originally contained 11 cubic centimetres so that the absorption must have ceased after it had reached about 65·4% of the oxygen originally present.

In order to show that the oxygen was not absorbed by the pyrite in the coal, Dr. Richters calculated the possible maximum amounts of pyrite in the three seams by assuming the ash to be wholly ferrous sulphide. This gave Carl seam 0·31%, Robert seam 0·42%, and Jacob seam 0·36%, all the coals being very low in pyrite. Quartz sand was then mixed with pyrite so that the mixture had the same pyrite contents as the coals and the experiments were repeated on this mixture instead of the coals. In the first case when dry air was used no oxygen was absorbed, and in the second, using moist air, only a very small quantity even when the mixture was left in contact with air for a very long time.

**Haldane and Meachem**, who seem to lean to the opinion that the absorption is largely mechanical at first, studied the action of air on coal, by a series of laboratory experiments. In the first instance coal was crushed in a mortar and placed in a thick walled flask closed by a rubber cork soaked in paraffin through which there was a bent glass tube to form a manometer. The limbs of this tube were half filled with mercury. The flask was immersed in a water bath so that its temperature was known, and the manometer, barometer and thermometer recorded for a long period of time. It will be sufficient to quote one of the experiments made with this apparatus. (Tables X and XI.)

The coal used was from "Bough's bolt hole", Hamstead colliery, sent up three months previously and allowed to lie in lumps in the laboratory since that time. The coal was crushed in a mortar and left spread out in a thin layer for two hours before it was placed in the flask and sealed. The pressures given are corrected for atmospheric temperature and pressure.

TABLE X.  
Absorption of Oxygen by Coal in a Closed Vessel.

(Haldane and Meachem)

Time since closing flask	Negative pressure of mercury	Time since closing flask	Negative pressure of mercury
Hours	Inches	Days	Inches
1	0·15	4	5·05
5	0·65	5	5·45
12	1·25	6	5·75
24	2·00	7	6·00
36	2·80	9	6·10
48	3·40	11	6·10
56	3·85	24	6·00
72	4·30	6 months	5·85

A sample of gas was then withdrawn and analysed. The results of this analysis were:—

TABLE XI.  
Composition of Residual Gases in Vessel.

(Haldane and Meachem)

Oxygen.....	0·066%
Carbon dioxide.....	1·286%
Firedamp.....	0·651%
Carbon monoxide.....	0·042%
Nitrogen.....	97·957%
Total.....	100·002%

Assuming that only oxygen is absorbed by the coal and that no nitrogen is evolved this analysis would indicate a diminution of pressure of 19·3 per cent. When the flask was closed the barometer was at 29·75 inches and the diminution in pressure was 5·85 inches, or 19·6 per cent of 25·95 inches. An even closer check was obtained in another experiment made with similar coal under similar conditions.

Some experiments were then made to obtain quantitative data on the rate of oxidation of coal and the effect of variation of temperature on the rate of oxidation. The apparatus used consisted of a vessel with two tightly fitted perforated corks, one at each end. Through the lower cork a current of pure air was introduced. The bottom of the vessel was covered with pumice stone and the coal was placed in a thick layer on top of this with a view to securing an even stream of air through the coal.

The air, on leaving the vessel, passed through a smaller vessel which could be disconnected at any time and its contents analysed. The air then passed through a small meter and thence to an aspirator. The vessels were both fully immersed in the water bath and the temperature was kept constant for at least one hour before any sample of air was taken for analysis. The results of two experiments are shown in Tables XII and XIII.

TABLE XII.

## ABSORPTION OF OXYGEN.

Experiment I with 0·92 pounds of finely crushed coal sent from the pit 4 days previously and crushed just before the experiment.

(Haldane and Meachem)

Temper- ature of bath	Time since coal was crushed	Rate of ventilation per hour	Deficiency of oxygen	Carbonic acid increased	Fire damp and carbonic oxide	Oxygen absorbed per ton of coal and per hour
Degs. C.	Hours	Cubic feet	Per cent	Per cent	Per cent	Cubic feet
15	2	0·091	1·10	0·07	0·290	2·45
15	5	0·131	0·72	0·02	—	2·30
15	8	0·080	1·00	0·05	—	1·95
16	20	0·114	0·46	0·04	—	1·26*
38	25	0·114	1·29	0·05	0·075	3·58
42	29	0·114	1·48	0·12	0·100	4·11
52	32	0·103	2·18	0·10	0·110	5·59

\*Ventilation left on for 12 hours since last determination.

TABLE XIII.

## ABSORPTION OF OXYGEN.

Experiment II with 2·7 pounds of crushed coal (same sample as used in last experiment) sent from pit 3 months previously and fragments crushed a few hours before the experiment.

(Haldane and Meachem)

Temper- ture of bath	Rate of ventilation per hour	Deficiency of oxygen	Carbonic acid increased	Fire damp	Carbonic oxide	Oxygen absorbed per ton of coal and per hour
Degs. C	Cubic feet	Per cent	Per cent	Per cent	Per cent	Cubic feet
15	0·078	0·40	0·09	0·00	0·00	0·26
71	0·084	5·31	0·67	0·07	0·14	3·70

These experiments show clearly that the coal continuously absorbs oxygen from the air, but that this absorption is at a decreasing rate as time passes, so long as the temperature is constant. The rate increases, however, very considerably as the temperature rises.

It should also be noted in passing that the evolution of carbonic acid while continuous is somewhat erratic, and is in all cases very small as compared with the amount of oxygen absorbed.

Table XIV shows the result of an experiment by Haldane and Meachem to determine the effect of sealing off a sample of coal with a limited quantity of air. The rate of absorption of oxygen was comparatively rapid at the start, but decreased steadily and with considerable uniformity. This decrease is ascribed by them to the decrease in the pressure of the remaining oxygen in the flask, and no doubt it is partly due to this, but the first four lines of Table XII show that a similar decrease in rate occurs with time, even when the oxygen supply is constant. The calculations which Haldane and Meachem make as to the probable rate of absorption under various conditions would, therefore, seem to lose a part of their value.

TABLE XIV.  
Absorption of Oxygen at Reduced Pressures.

(Haldane and Meachem)

Period	Mean partial pressure of oxygen in percentage of 1· Atmospheres. Pressure.	Oxygen absorbed	
		Observed	Calculated
		Per cent	Per cent
First 24 hours.....	17·6	6·7	6·7
Second 24 hours.....	11·9	4·7	4·5
Third 24 hours.....	7·9	3·1	3·1
Fourth 24 hours.....	5·2	2·5	2·1
Fifth 24 hours.....	3·2	1·3	1·3
Sixth 24 hours.....	2·1	1·0	0·8

Porter and Ovitz<sup>1</sup> believe that the absorption of oxygen by coal is chemical rather than mechanical. This opinion is largely based on an experiment with Benton, Illinois coal (No. 49):—

“After being supplied with oxygen for five months, during which time it combined with oxygen equal in volume to nearly seven times its own volume, a sample of the coal was placed in a flask in boiling water. The gases evolved during 15 minutes boiling, showed no excess of oxygen over that contained in the air”.

The experiment outlined above shows that the oxygen absorbed was not merely occluded at the end of its five months' contact with the coal, but it does not prove that occlusion was not the first step in the process. It should also be noted as Stansfield<sup>2</sup> has already pointed out,

“that when the coal is heated to drive out any oxygen occluded, the experiment becomes unreliable, as, at the higher temperatures the occluded oxygen would react so readily with the coal that there would be little chance of its being evolved”.

The series of experiments is, however, so interesting that a summary description of them is appended.

<sup>1</sup> Technical paper II. U. S. Bureau of Mines, 1911. “The escape of gas from coal.”

<sup>2</sup> The Coals of Canada. Vol. VI, 1912, p. 109.

The method of procedure adopted was as follows:—

“A sample of about 10 kilogrammes of coal was taken from a clean fresh face of the seam in the manner prescribed, by the U. S. Bureau of Mines<sup>1</sup>; for mine sampling. This sample was crushed so as to pass a  $\frac{1}{2}$ -inch screen, and placed in a 5-gallon crated glass bottle, which was then stoppered as quickly as possible—usually within 50 to 80 minutes after beginning the cut. A tight fitting rubber stopper was wired in. Through the stopper passed a 20 cm.length of glass tubing of 2 mm.bore, its outer end being sealed by a piece of heavy rubber tubing and a solid glass plug. The crushed coal consisted largely of small lumps between one-tenth and one-half inch in size, but contained 10 to 20 per cent of material under one-tenth inch in size. The bottle was shipped forthwith to the laboratory at Pittsburg. As soon as it arrived there the rubber stopper connections were painted with shellac to avoid all risk of leakage, and a gas sample was at once withdrawn for analysis. The bottles were then allowed to stand in the laboratory for several months at a temperature varying from 12° to 32°.

Four coals, No. 37 (Pocahontas, Va.) No. 39 (Harrisburg, Ill.), No. 43 (Sheridan, Wyo.) and No. 49 (Benton, Ill.), were subjected to further investigation as follows. “The bottle of Pocahontas coal was connected through the glass tube in the stopper to a reservoir of oxygen, so that oxygen flowed into the bottle as fast as it was absorbed by the coal. From time to time the gas that accumulated in the bottle was drawn out in order to relieve the pressure and permit the inflow of oxygen. The bottles containing coals No. 39 and 43 were connected to a supply of air instead of oxygen and the inlet tube extended to the centre of the coal in each bottle. There also was attached to each of these two bottles a collecting reservoir for the escaping gas, the connecting tube for this purpose passing from the top of the bottle to the reservoir. The bottle of Benton, Ill. coal (No. 49) was connected with both an oxygen supply and a gas collecting reservoir, but oxygen not air was admitted to the bottle and was admitted at the top, the gas being withdrawn from underneath the coal”.

A number of other coals were tested in a somewhat similar manner, occasional samples of gas being taken from the bottles, but without drawing off the accumulated gas into collecting reservoirs or admitting a supply of oxygen.

The results of these tests are shown in Tables XV, XVI and XVII.

TABLE XV.

**Descriptive list of coals tested.**

(Porter and Ovitz)

Coal No.	Kind of coal	State	County	Place	Name of coal bed	Mine
29	Bituminous....	Wyo.	Sweetwater..	Rock Springs	Rock Springs	No. 1.
30	“ .....	Do.	Carbon.....	Hanna.....	Lower.....	No. 2.
33	“ cannel	Ky. .	Johnson.....	Paintsville...	.....	Flambeau.
35	“ .....	W. Va.	Marion.....	Monongah ..	Pittsburg....	No. 6.
37	Semi-bituminous.....	Va....	Tazewell.....	Pocahontas..	No. 3.....	Baby.
39	Bituminous....	Ill....	Saline.....	Harrisburg...	No. 5.....	No. 9.
41	Bituminous....	Pa....	Fayette.....	Connellsville.	Pittsburg....	Leisenring No. 1
43	Semi-bituminous.....	Wyo.	Sheridan.....	Sheridan.....	No. 9.....	Dietz No. 2
49	Bituminous....	Ill....	Franklin.....	Benton.....	No. 7.....	Hart-Williams.

<sup>1</sup> Technical Paper I. U. S. Bureau of Mines, 1911. “The Sampling of Coal in the Mine.”

TABLE XVI.  
Absorption of Oxygen by Coal.

(Porter and Ovitz)

Coal	Weight of coal	Period of time	Oxygen removed	Oxygen admitted	Vol. of Oxy- gen absorbed ÷ Vol. of coal (a) (c)
Pocahontas, Va.... (No. 37)	Kilos 13.4		c.c.	c.c.	
		First 31 days.....	37	1,830	0.174
		Next 28 days.....	7	4,010	0.390
		Next 31 days.....	9	7,275	0.705
		Next 183 days.....	44	24,510	2.375
		Next 31 days.....	5	4,860	0.471
		10 months	102	42,485	4.115
Harrisburg, Ill..... (No. 39).	14.6	First 4 days.....	24	1,660	0.145
		Next 24 days.....	0	0	0.000
		Next 31 days.....	456	7,320	0.610
		Next 30 days.....	102	2,744	0.235
		Next 153 days.....	363	17,460	0.520
		Next 31 days.....	181	4,040	0.343
		9 months	1,126	33,224	2.853
Sheridan, Wyo..... (No. 43).	8.1	First 7 days.....	0	2,520	0.403
		Next 23 days.....	52	1,550	0.240
		Next 31 days.....	61	3,110	0.488
		Next 30 days.....	54	2,940	0.462
		Next 92 days.....	282	13,760	2.157
		Next 31 days.....	166	3,990	0.612
		7 months	615	27,870	4.362
Benton, Ill..... (No. 49)	12.2	First 15 days.....	0	2,040	0.220
		Next 15 days.....	34	4,610	0.494
		Next 62 days.....	844	33,700	3.532
		Next 30 days.....	603	10,970	1.113
		Next 31 days.....	872	15,520	1.576
		Next 365 days.....			
		17 months	2,353	66,840	6.935 (b)

(a) Relative volumes of gas are computed on the basis of the apparent specific gravity of the coal (taken as 1.3), this value being the average of a large number of determinations of small lump size (1-inch) coals. The volume occupied by 10 kilogrammes of coal is therefore taken as  $10/1.3 = 7.7$  litres. The volume of the pores in small lump coal, assuming an average absolute specific gravity of 1.45 may be computed as one-tenth of the volume of the lumps, that is  $(1.45 - 1.30) \div 1.45 = 0.103$ .

(b) Total for five months only.

(c) Oxygen from air in case of Nos. 39 and 43. Oxygen 95% pure, in case of Nos. 37 and 49. The great irregularities in the rate of absorption of oxygen are due to the irregular admission of oxygen.

TABLE XVII.

## Absorption of Oxygen by the above coals in closed vessels.

(Porter and Ovitiz)

Coal No.	Period of time	Oxygen absorbed	Vol. of oxygen absorbed ÷ Volume of coal
		c.c.	
29.....	First 22 days.....	2,500	0·313
	Next 9 days.....	0	.....
30.....	First 10 days.....	2,500	0·313
	Next 21 days.....	0	.....
33.....	First 24 days.....	2,500	0·313
	Next 249 days.....	.....	.....
35.....	First 4 days.....	2,300	0·288
	Next 26 days.....	.....	.....
41.....	First day.....	1,080	0·135
	Next 10 days.....	1,220	0·153
	Next 415 days.....	.....	.....

The figures in Table XVI do not permit of any trustworthy estimate of the rate at which coal absorbs oxygen, due to the fact that it was found, late in the course of the experiment, that the degree of concentration of the oxygen had a great influence on the rate of absorption. Ordinary air had been used in some of the tests and 95% pure oxygen in others. In all cases, however, a rapid and long-continued absorption is shown, and there was little or no evolution of carbon dioxide.

The volume of air enclosed with the coal in the 5 gallon bottles used to contain the samples was a little over 11 litres. Thus there were originally present about 2,500 cubic centimetres of oxygen in each with about three times this volume of coal. Samples of the air from some of these bottles were withdrawn from time to time and analysed and the results, which are given in Table XVII, show that virtually all of the oxygen was absorbed quite soon, for example, coal No. 41 absorbed slightly more than half of the amount in one day; at the same time it evolved little more than one-tenth as much carbon dioxide as would have been formed if all the oxygen absorbed had combined with carbon to form carbon dioxide.

**Parr and Barker**<sup>1</sup> experimenting with Illinois coals obtained results showing a large absorption of oxygen. Their tests may be summarized as follows: coal drillings were sealed for twelve months in jars with volumes of air equal to from six to ten times the volume of the coal. After one year the air was withdrawn and analysed. The coals used were:—

1. Springfield, Sangamon Mine, Sangamon Coal Co.
2. Springfield, Sangamon Mine, Sangamon Coal Co.
3. Eldorado, Mine No. 8, O'Gara Coal Co.
4. Marion, Chicago and Big Muddy Coal Co.

<sup>1</sup> Univ. of Illinois Eng. Expt. Station Bulletin No. 32, 1909.

5. Herrin, Squirrel Ridge Mine, Chicago and Cartierville Coal Co.
6. Du Quoin, Greenwood, Davis Coal Co.
7. Belleville, Suburban Coal Mining Co.
8. O'Fallon, Mine No. 2, Louis and O'Fallon Coal Co.

TABLE XVIII.

**Absorption of Oxygen by Illinois Coals.***(Parr and Barker)*

Sample	I	II	III	IV	V	VI	VII	VIII
Wt. of coal (grms.).....	109	139	180	183	146	134	138	153
Total volume of gas enclosed in c.c.....	873	849	816	814	843	853	850	837
Oxygen %.....	0.16	0.13	0.00	0.00	0.25	0.00	0.00	1.45
Nitrogen %.....	99.36	98.93	93.04	98.13	97.33	98.77	98.99	96.93

**Parr and Wheeler**<sup>1</sup> have done very valuable work on the losses in calorific value of Illinois coals due to oxidation, which they conclude to range from 1.3% to 3.4% over a period of ten months. In view of the importance of their work no apology is necessary for the following somewhat extended abstract of their published report now out of print.

The coals used for the principal series of tests were from Sangamon, Williamson and Vermilion counties. Car load lots both of nut coal and screenings were procured and one-half of each was piled out of doors to a depth of 3½ feet in rough bins with earth floors. The other half-carloads were put in covered wooden bins with board floors raised about eighteen inches above the ground. The coal in these bins was partly exposed on two sides. Other portions of these coals were placed in large earthenware jars holding one hundred pounds each, and after being covered with water were stored in a cellar having a temperature of about 70 degrees Fahrenheit.

In addition to the above coals, samples were obtained from piles 3-7 feet deep containing not over 500 tons of screenings from Christian and Fulton counties; these piles had been entirely exposed for six months: and from large piles of Williamson and Franklin county coals belonging to the Commonwealth Edison Co., one containing 25,000 tons of egg coal between 3 and 6 in. diameter, another 3,500 tons of nut, and a third 4,500 tons of washed No. 1. Samples were also obtained from a fifteen ton lot of Vermilion county coal which had been piled on the ground for two and a half years and analysed from time to time, and finally some mine pillars over 25 years old, and a natural outcrop<sup>2</sup> in Peoria county, were accurately sampled.

Since it is impossible to sample any lot of coal exactly as regards ash and sulphur, all B.Th.U. determinations were referred to the actual coal

<sup>1</sup> Univ. of Ill. Eng. Exp. Sta. Bull. 38, 1909.

<sup>2</sup> See page 169, this volume.

basis for the sake of comparison. In order to do this the following formula was used.

$$\frac{\text{B.Th.U. as determined} - 5000 \times \text{Weight of Sulphur.}}{1.00 - (\text{Moisture} + 1.08 \times \text{ash} + (22 \div 40) \times \text{Sulphur})}$$

"In explanation of the terms of this formula it may be stated that "5000  $\times$  Weight of Sulphur" in pounds per pound of coal represents the heating value of the sulphur in B. Th. U. This is deducted from the heating

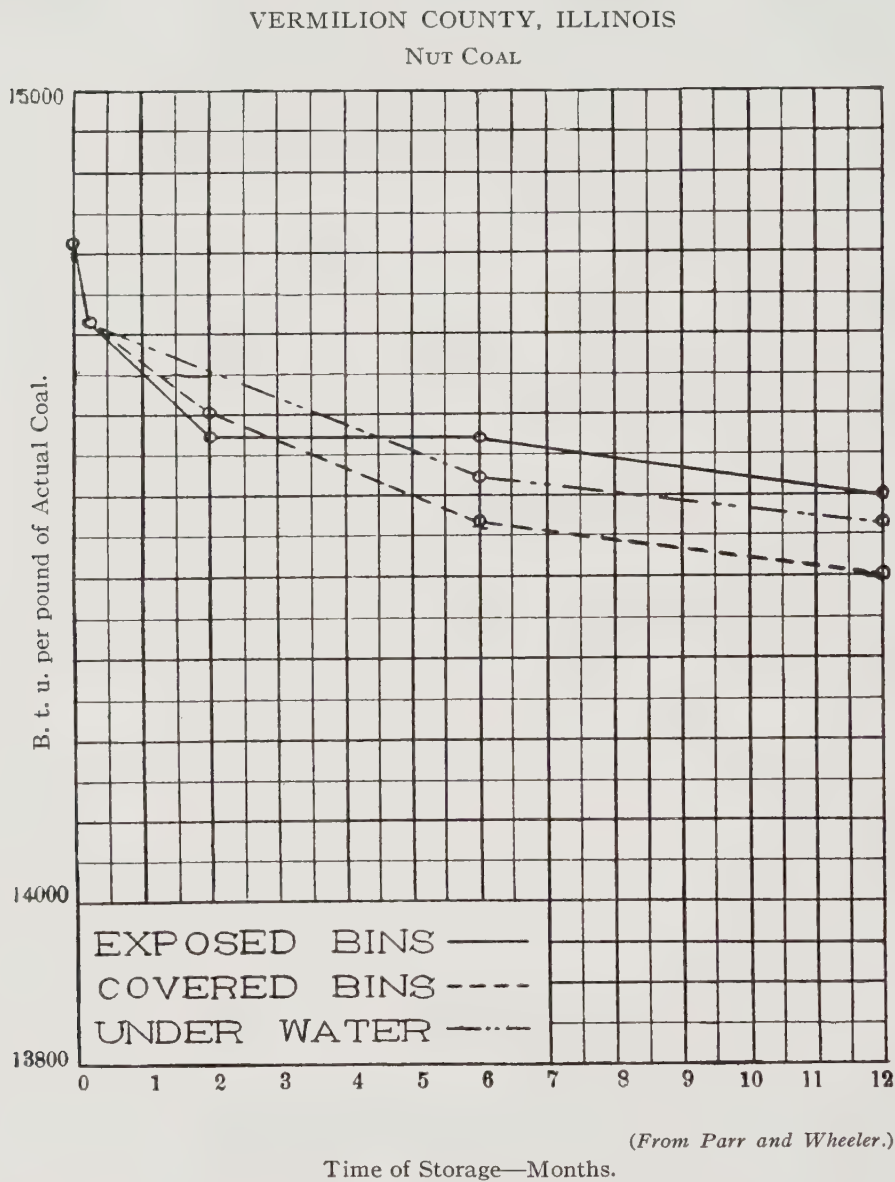


FIG. 14. Calorific power stored coal.

value of the coal given by the calorimeter in order to overcome any variation in the amount of sulphur present in the several samples. The term "1.08  $\times$  ash" represents the mineral matter of the coal that remains after burning completely and also an additional eight per cent for the water and carbon dioxide that were not part of the coal, but which combined with the mineral matter of the ash and thus took the place of an equal

TABLE XIX.

## Calorific Losses in Storage, Vermilion County, Illinois, Nut Coal.

*(Parr and Wheeler)*

Sample taken	Dry coal			B.Th.U. referred to actual or unit coal	Decrease	
	Ash	Sulphur	B.Th.U.		B.Th.U.	Per cent

## STORED IN EXPOSED BINS.

Same day as mined .....	10.55	4.25	12,991	14,814	—	—
7 days after mining.....	13.98	2.65	12,412	14,716	98	0.66
2 months after mining.....	14.21	2.47	12,265	14,577	237	1.60
6 months after mining.....	13.53	2.10	12,396	14,575	239	1.61
12 months after mining.....	13.62	2.82	12,282	14,498	316	2.13

## STORED IN COVERED BINS.

Same day as mined.....	10.55	4.25	12,991	14,814	—	—
7 days after mining.....	13.98	2.65	12,412	14,716	98	0.66
2 months after mining.....	13.08	2.13	12,475	14,604	210	1.42
6 months after mining.....	11.76	2.14	12,571	14,472	342	2.31
12 months after mining.....	13.52	2.72	12,220	14,403	411	2.77

## STORED UNDER WATER.

Same day as mined.....	10.55	4.25	12,891	14,814	—	—
Same day as submerged.....	13.98	2.65	12,412	14,716	98	0.66
6 months after mining.....	15.37	3.34	12,013	14,526	290	1.96
12 months after mining.....	13.85	3.81	12,231	14,517	297	2.00

weight of actual coal. The last term " $(22 \div 40) \times \text{Sulphur}$ " represents the sulphur corrected for the oxygen that replaces it in the ash. When the coal is burned, any sulphur that was combined with iron as pyrite is replaced by oxygen leaving  $\text{Fe}_2\text{O}_3$  in the ash. This exchange results in a loss of weight of only five-eighths of the amount of sulphur burned; since, however, part of the sulphur is not in the form of pyrite, but in a non-combustible form which may remain in the ash, the fraction  $22 \div 40$  is used instead of  $\frac{5}{8}$ . The denominator, therefore, in the above formula, is the weight of actual coal in a unit weight of coal as analysed."

WILLIAMSON COUNTY, ILLINOIS  
NUT COAL

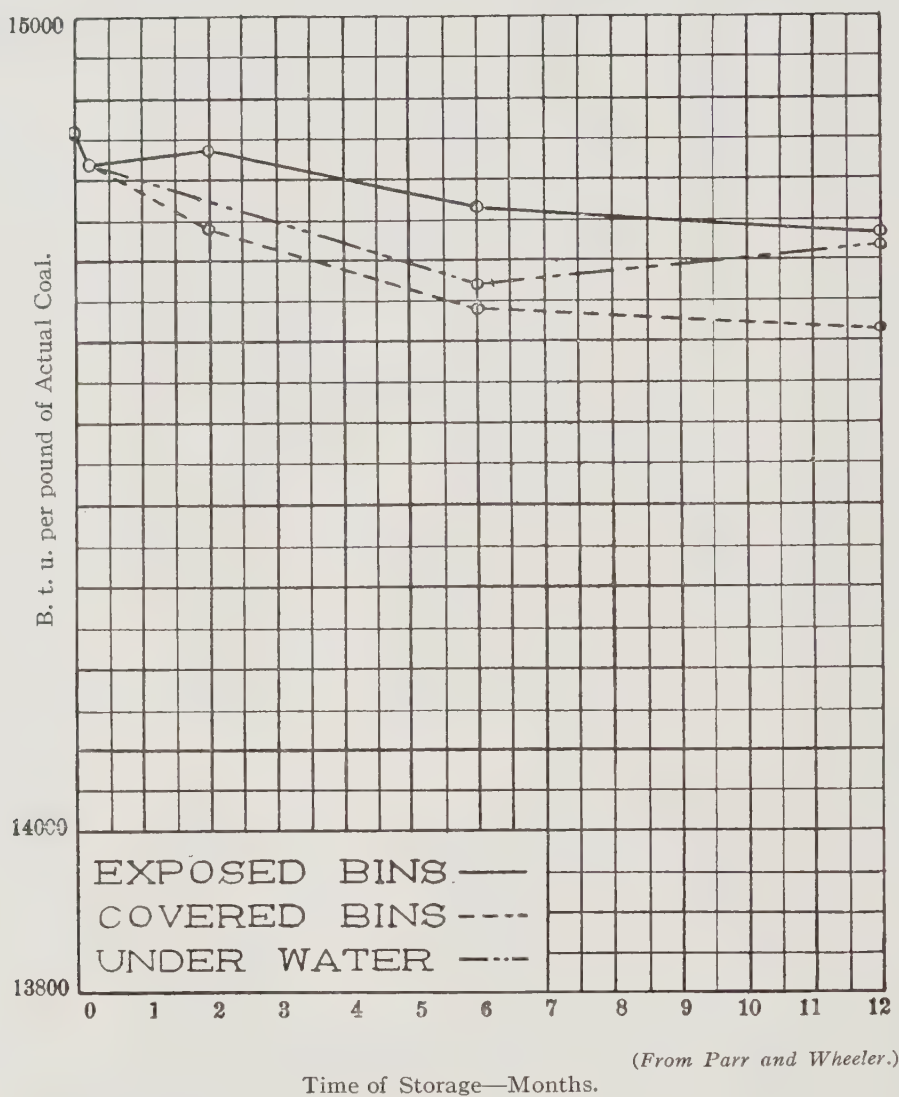


FIG. 15. Calorific power stored coal.

Tables XIX to XXVIII show the results obtained from these tests. The calorific values from the tables have been plotted (Figs 14 to 21) and the curves show very clearly the loss of calorific value due to weathering. In nearly all cases the screenings show a greater loss of calorific value than the nut coal. None of the coals used for these experiments, however, show a loss of calorific value which would warrant the storage of the coal under water; nevertheless the tests show very clearly that this method of storage decreases the weathering losses.

TABLE XX.  
Calorific losses in Storage, Williamson County Nut Coal.  
(Parr and Wheeler)

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.

STORED IN EXPOSED BINS.

Same day as mined.....	13.98	3.73	12,499	14,859	—	—
7 days after mining.....	14.90	3.02	12,341	14,821	38	0.26
2 months after mining.....	14.32	4.12	12,409	14,835	24	0.16
6 months after mining.....	13.81	3.43	12,455	14,765	95	0.64
12 months after mining.....	11.88	2.73	12,759	14,734	125	0.84

STORED IN COVERED BINS.

Same day as mined.....	13.98	3.73	12,499	14,859	—	—
7 days after mining.....	14.90	3.02	12,341	14,821	38	0.26
2 months after mining.....	14.08	3.84	12,378	14,739	120	0.81
6 months after mining.....	13.06	3.60	12,469	14,644	215	1.45
12 months after mining.....	13.24	3.20	12,428	14,616	243	1.64

STORED UNDER WATER.

Same day as mined.....	13.98	3.73	12,499	14,859	—	—
Same day as submerged.....	14.90	3.02	12,341	14,821	38	0.26
6 months after mining.....	15.65	3.12	12,097	14,673	186	1.25
12 months after mining.....	14.87	3.42	12,251	14,721	138	0.93

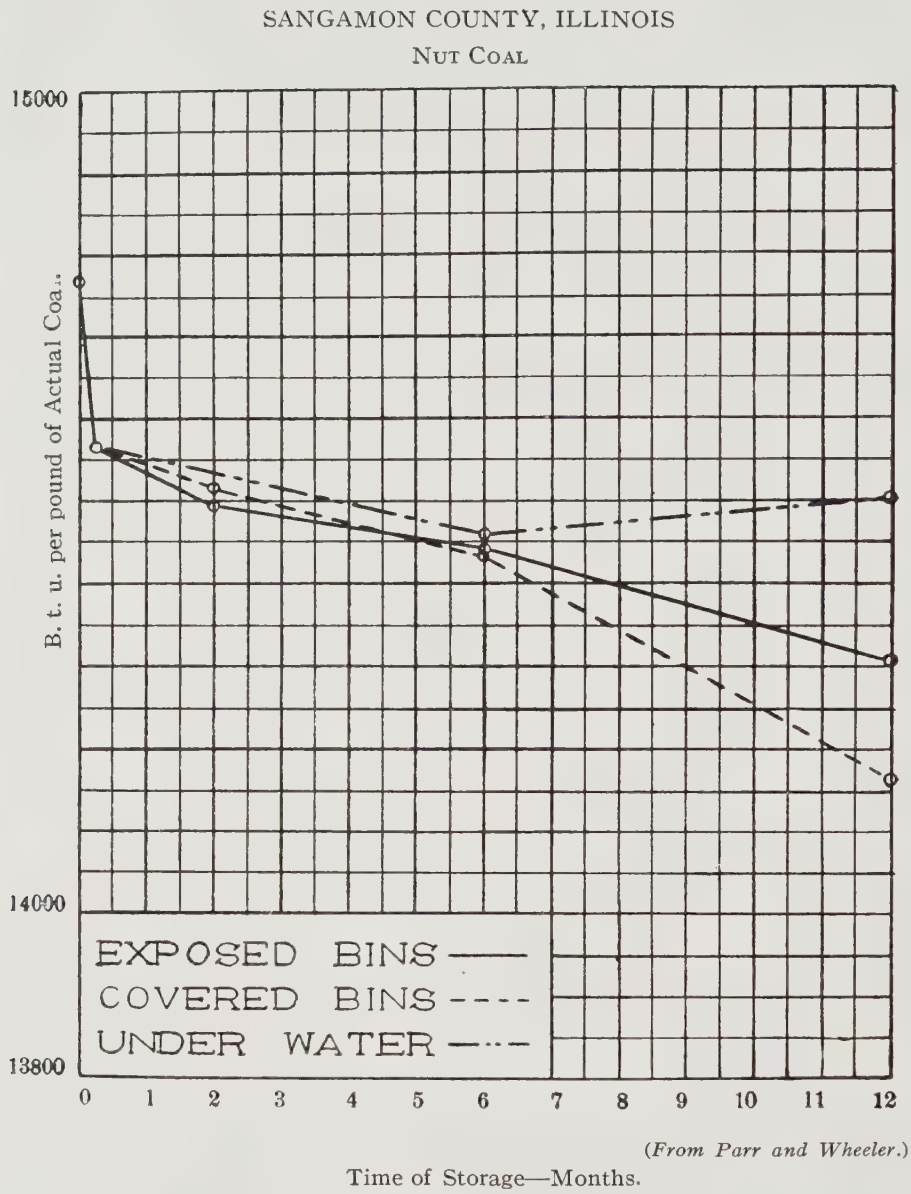


FIG. 16. Calorific power stored coal.

TABLE XXI.

## Calorific losses in Storage, Sangamon County, Illinois, Nut Coal.

*(Parr and Wheeler)*

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.

## STORED IN EXPOSED BINS.

Same day as mined.....	17.87	5.75	11,741	14,773	—	—
7 days after mining.....	16.63	5.10	11,800	14,571	202	1.37
2 months after mining.....	17.45	4.66	11,626	14,497	276	1.87
6 months after mining.....	16.03	4.91	11,798	14,444	329	2.23
12 months after mining.....	14.97	4.68	11,860	14,307	466	3.15

## STORED IN COVERED BINS.

Same day as mined.....	17.87	5.75	11,741	14,773	—	—
7 days after mining.....	16.63	5.10	11,800	14,571	202	1.37
2 months after mining (sample a) ..	16.08	5.03	11,912	14,600	173	1.17
2 months after mining (sample b) .	17.57	5.01	11,626	14,535	238	1.61
6 months after mining.....	16.30	4.52	11,682	14,336	437	2.96
12 months after mining.....	15.99	4.65	11,589	14,165	608	4.12

## STORED UNDER WATER.

Same day as mined.....	17.87	5.75	11,741	14,773	—	—
Same day as submerged.....	16.63	5.10	11,800	14,571	202	1.37
6 months after mining.....	15.90	4.21	11,854	14,461	322	2.18
12 months after mining.....	15.95	5.11	11,851	14,503	270	1.83

VERMILION COUNTY, ILLINOIS  
SCREENINGS

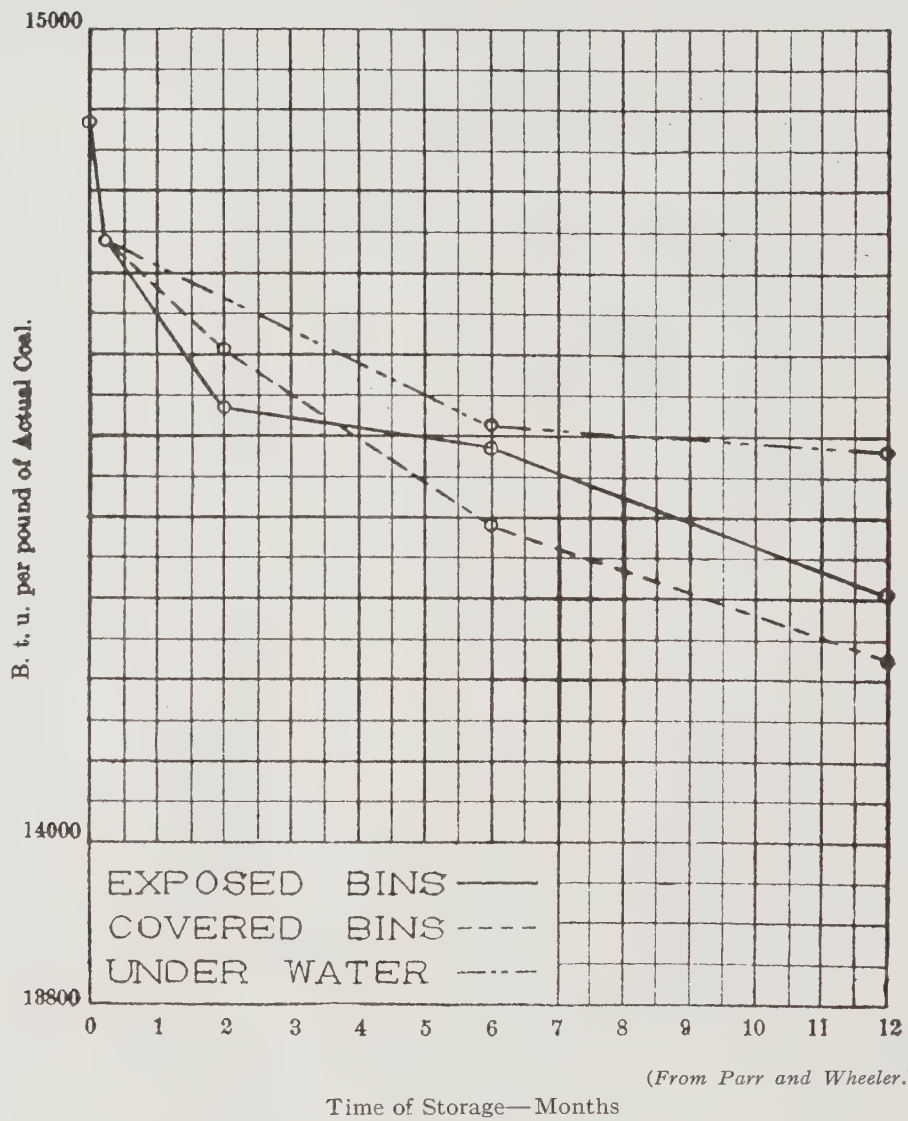


FIG. 17. Calorific power stored coal.

TABLE XXII.

## Calorific losses in Storage, Vermilion County, Illinois, Screenings.

*(Parr and Wheeler)*

Sample taken.	Dry coal			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.

## STORED IN EXPOSED BINS.

Same day as mined.....	17.88	2.35	11,937	14,888	—	—
7 days after mining (sample a)....	13.98	2.87	12,414	14,726	162	1.09
7 days after mining (sample b)....	13.69	2.29	12,507	14,759	129	0.87
2 months after mining (sample a) .	15.73	2.53	11,958	14,497	391	2.63
2 months after mining (sample b)..	14.69	2.90	12,178	14,578	310	2.08
6 months after mining.....	15.63	2.44	11,969	14,487	401	2.69
12 months after mining.....	14.46	2.24	12,006	14,304	584	3.92

## STORED IN COVERED BINS.

Same day as mined.....	17.88	2.35	11,937	14,888	—	—
7 days after mining (sample a)....	13.98	2.87	12,414	14,726	162	1.09
7 days after mining (sample b)....	13.69	2.29	12,507	14,769	129	0.87
2 months after mining.....	15.26	2.51	12,124	14,608	280	1.88
6 months after mining.....	14.51	2.25	12,071	14,391	497	3.34
12 months after mining.....	15.36	2.42	11,797	14,225	663	4.46

## STORED UNDER WATER.

Same day as mined.....	17.88	2.35	11,937	14,888	—	—
Same day as submerged (sample a)	13.98	2.87	12,414	14,726	162	1.09
Same day as submerged (sample b)	13.69	2.29	12,507	14,759	129	1.87
6 months after mining.....	13.87	2.32	12,270	14,514	374	2.51
12 months after mining.....	13.55	2.71	12,283	14,488	405	2.72

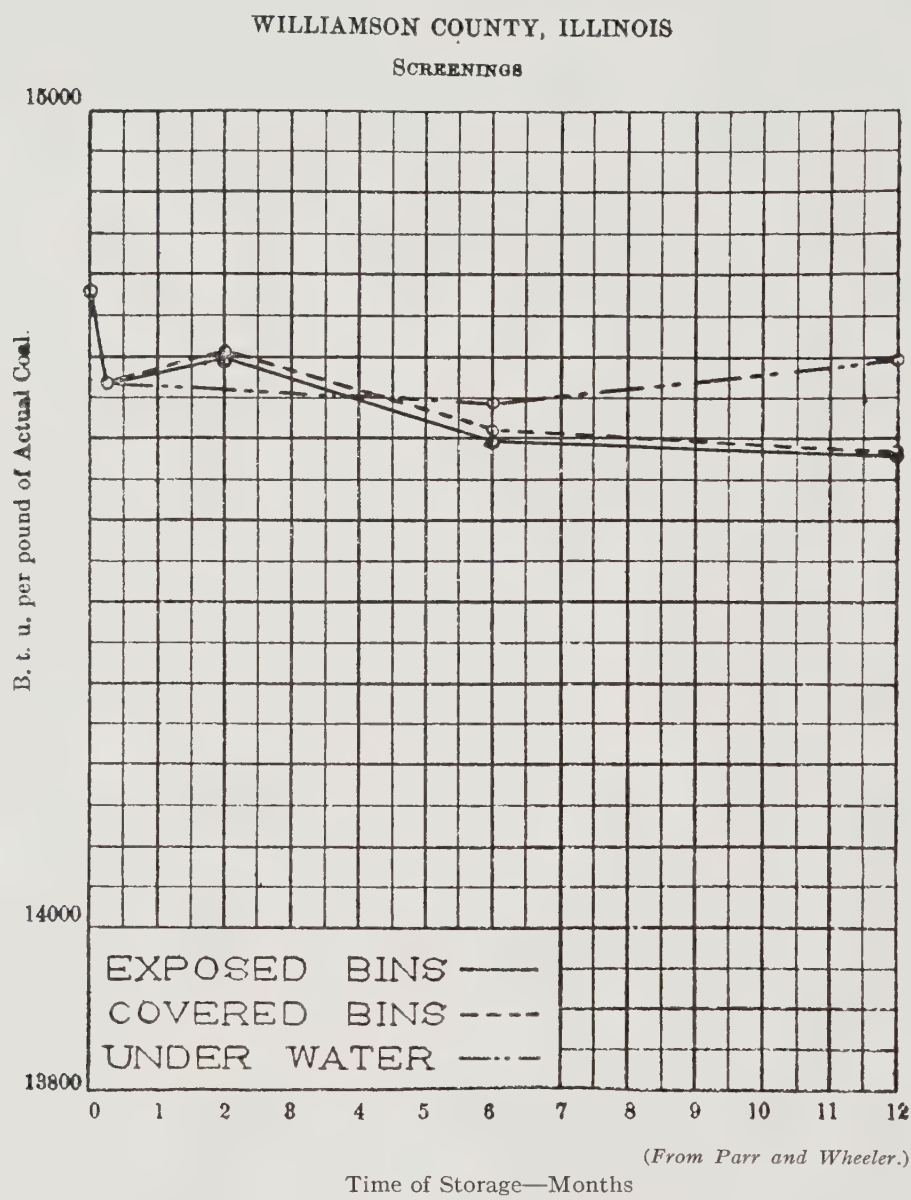


FIG. 18. Calorific power stored coal.

TABLE XXIII.

## Calorific losses in Storage, Williamson County, Illinois, Screenings.

*(Parr and Wheeler)*

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.

## STORED IN EXPOSED BINS.

Same day as mined.....	14.13	3.17	12,426	14,782	—	—
7 days after mining.....	14.37	3.34	12,287	14,666	116	0.78
2 months after mining.....	15.66	2.67	12,133	14,701	81	0.55
6 months after mining.....	13.76	2.84	12,342	14,597	185	1.25
12 months after mining.....	13.77	2.75	12,328	14,579	203	1.37

## STORED IN COVERED BINS.

Same day as mined.....	14.13	3.17	12,426	14,782	—	—
7 days after mining.....	14.37	3.34	12,287	14,666	116	0.78
2 months after mining.....	12.62	2.98	12,608	14,705	77	0.52
6 months after mining.....	13.60	3.03	12,372	14,610	172	1.16
12 months after mining.....	13.43	2.72	12,385	14,582	200	1.35

## STORED UNDER WATER.

Same day as mined.....	14.13	3.17	12,426	14,782	—	—
Same day as submerged .....	14.37	3.34	12,287	14,666	116	0.78
6 months after mining.....	14.38	3.54	12,262	14,645	137	0.93
12 months after mining.....	13.60	2.97	12,447	14,698	84	0.57

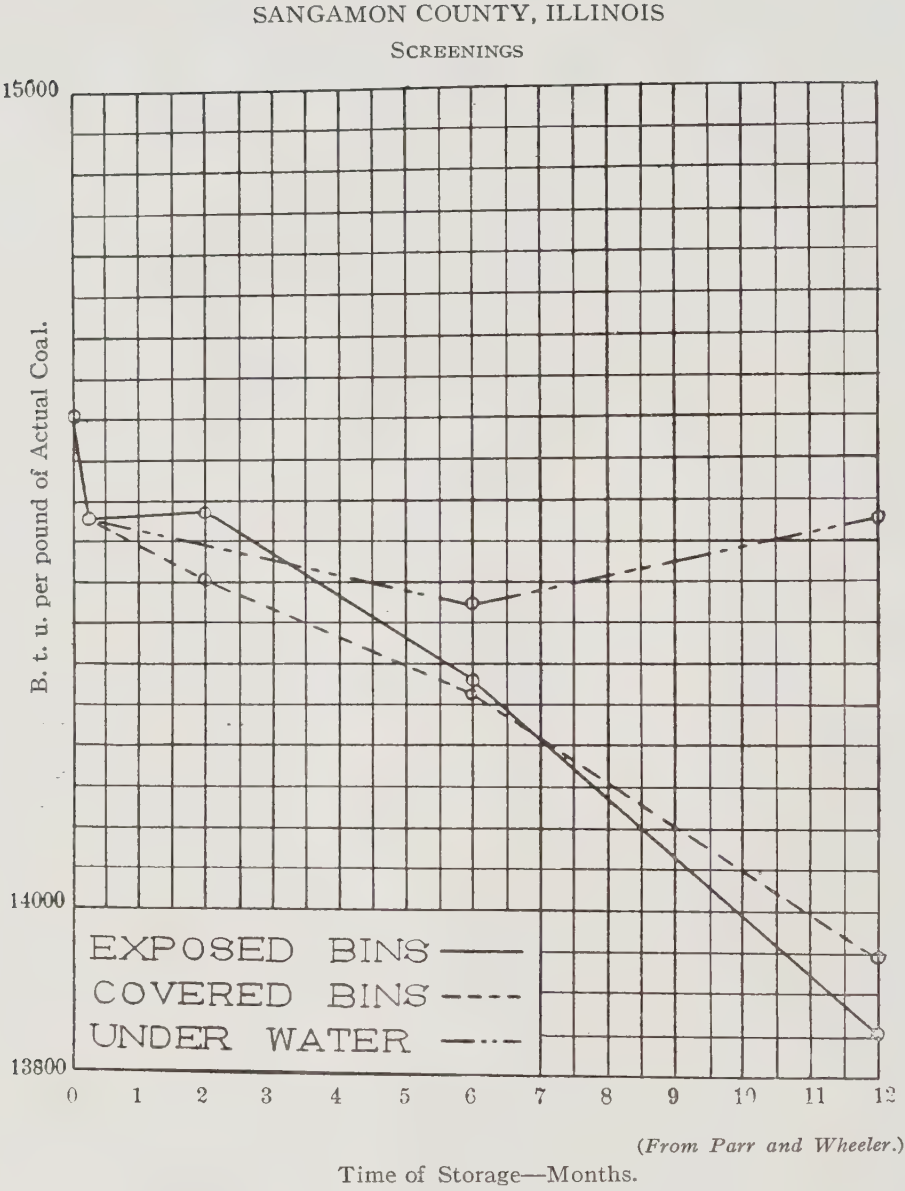


FIG. 19. Calorific power stored coal.

TABLE XXIV.

## Calorific losses in Storage, Sangamon County, Illinois, Screenings.

*(Parr and Wheeler)*

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.

## STORED IN EXPOSED BINS.

Same day as mined.....	17·13	4·92	11,752	14,604	—	—
7 days after mining.....	17·04	4·47	11,684	14,481	123	0·84
2 months after mining.....	17·22	5·00	11,645	14,488	116	0·79
6 months after mining.....	17·02	4·54	11,526	14,281	323	2·21
12 months after mining.....	17·25	4·54	11,153	13,853	751	5·14

## STORED IN COVERED BINS.

Same day as mined.....	17·13	4·92	11,752	14,604	—	—
7 days after mining.....	17·04	4·47	11,684	14,481	123	0·84
2 months after mining.....	18·33	4·70	11,414	14,404	200	1·37
6 months after mining.....	17·30	4·67	11,466	14,263	341	2·33
12 months after mining.....	17·06	4·73	11,248	13,944	660	4·52

## STORED UNDER WATER.

Same day as mined.....	17·13	4·92	11,752	14,604	—	—
Same day as submerged.....	17·04	4·47	11,684	14,481	123	0·84
6 months after mining.....	19·86	5·60	11,127	14,372	232	1·59
12 months after mining.....	18·27	4·81	11,479	14,478	126	0·86

AVERAGE VALUES FROM THE SIX PRECEDING FIGURES.

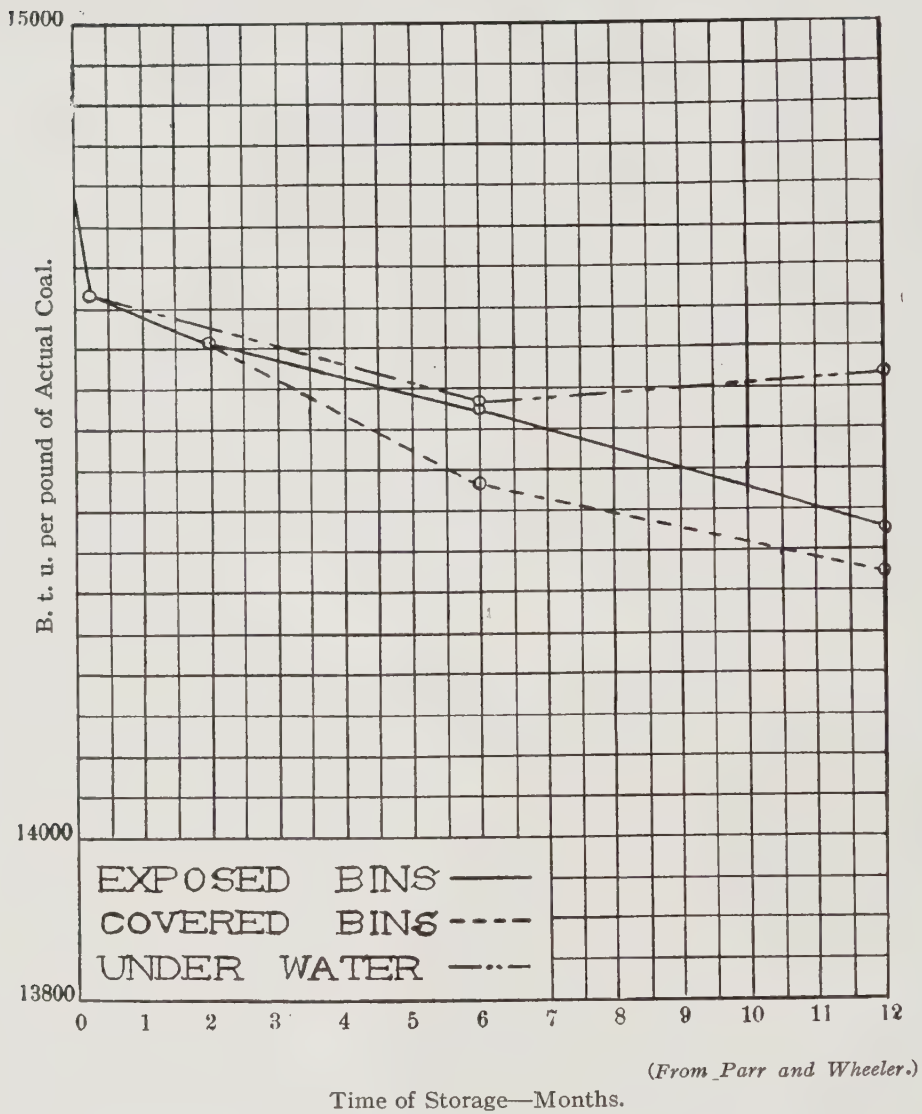


FIG. 20. Calorific power stored coal.

TABLE XXV.

Calorific losses in Storage, average values from six preceding tables.

*(Parr and Wheeler)*

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.

## STORED IN EXPOSED BINS.

Same day as mined.....	15·26	4·03	12,224	14,787	—	—
7 days after mining.....	15·13	3·53	12,164	14,666	121	0·82
2 months after mining.....	15·68	3·61	12,024	14,606	181	1·22
6 months after mining.....	14·96	3·36	12,081	14,525	262	1·77
12 months after mining.....	14·33	3·29	12,065	14,379	408	2·76

## STORED IN COVERED BINS.

Same day as mined.....	15·26	4·03	12,224	14,787	—	—
7 days after mining.....	15·13	3·53	12,164	14,666	121	0·82
2 months after mining.....	15·07	3·53	12,128	14,605	182	1·22
6 months after mining.....	14·42	3·37	12,105	14,453	334	2·26
12 months after mining.....	14·77	3·57	11,945	14,323	464	3·14

## STORED UNDER WATER.

Same day as mined.....	15·26	4·03	12,224	14,787	—	—
Same day as submerged.....	15·13	3·53	12,164	14,666	121	0·82
6 months after mining.....	15·84	3·69	11,937	14,532	255	1·73
12 months after mining.....	15·02	3·81	12,090	14,567	220	1·44

TABLE XXVI.

## Calorific losses in Storage, Christian County, Illinois, Screenings.

*(Parr and Wheeler)*

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.
When stored. (About 2 weeks after mining) . . . . .	19·20	5·04	11,325	14,475	—	—
5 months in exposed pile of about 500 tons (Had heated badly)	16·68	4·43	11,425	14,083	392	2·71

TABLE XXVII.

## Calorific losses in Storage, Fulton County, Illinois, Screenings.

*(Parr and Wheeler)*

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.
2 weeks after mining . . . . .	20·97	3·42	11,114	14,500	—	—
6 months in exposed pile 3 feet deep . . . . .	21·12	3·17	11,021	14,398	102	0·70

VERMILION COUNTY, ILLINOIS  
SCREENINGS

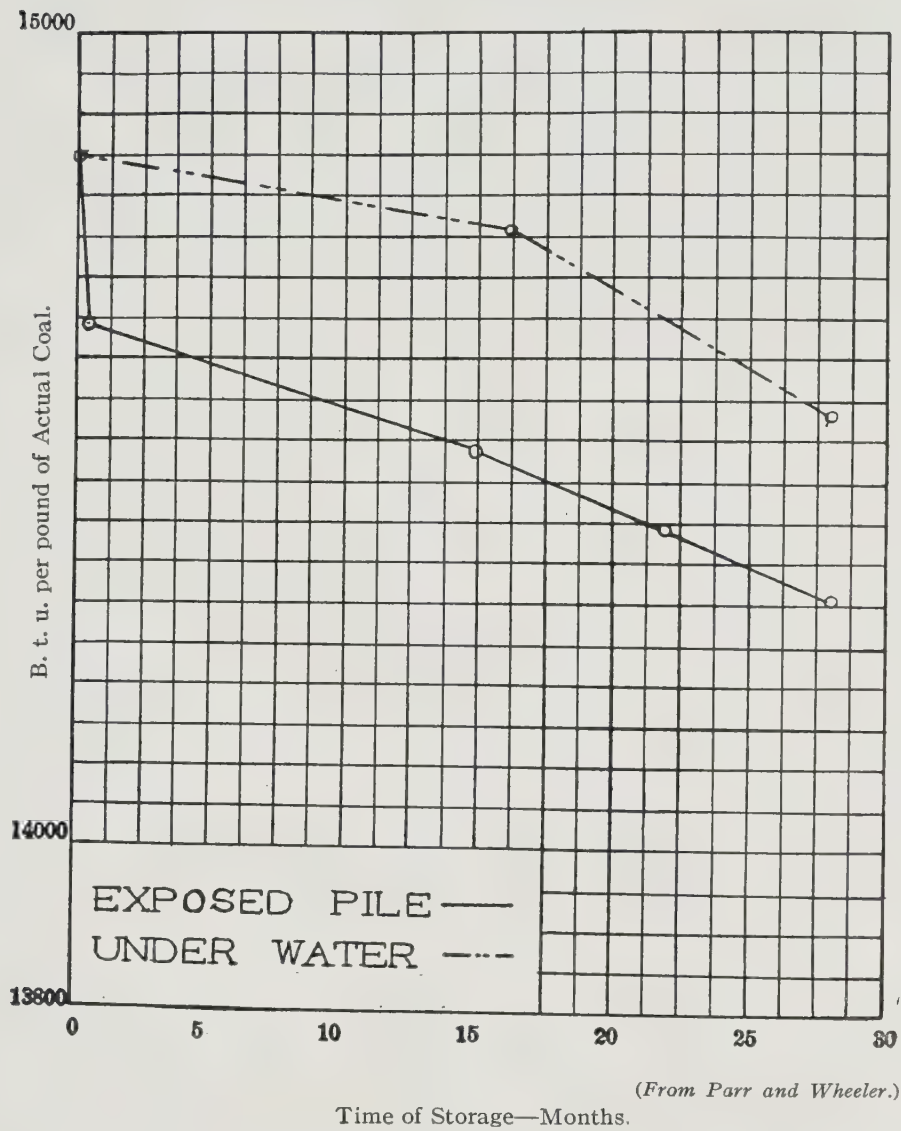


FIG. 21. Calorific power stored coal.

TABLE XXVIII.

## Calorific Losses in Storage, Vermilion County, Illinois, Screenings.

(Parr and Wheeler)

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.

## STORED IN EXPOSED PILE.

When mined.....	—	—	—	14,850*	—	—
About 2 weeks after mining.....	19·11	1·96	11,561	14,644	206	1·39
15 months after mining.....	19·54	2·20	11,368	14,491	359	2·42
22 months after mining.....	20·61	1·88	11,134	14,392	458	3·08
28 months after mining.....	21·70	1·83	10,901	14,307	543	3·66

## STORED UNDER WATER.

When mined.....	—	—	—	14,850	—	—
15 months after submerging.....	15·90	2·29	12,154	14,761	89	0·60
28 months after submerging.....	17·75	1·97	11,686	14,531	319	2·15

\*Calorific value taken from other analyses of fresh coal from same mine and neighbouring mine.

A valuable paper on oxidation by **Winmill**<sup>1</sup> has appeared as this volume is being prepared for the press, and the following extracts are included as they have a decided bearing on the subject under discussion. The paper describes the first<sup>2</sup> of a series of investigations undertaken by the Doncaster Coal-owners Association in England, who have undertaken a systematic study of their coal seams. In this first paper the results of four sets of experiments are set forth:—

(a) On the relative rates of oxidation of various parts of the Barnsley seam.

(b) On the effect of reducing the oxygen content of the intake air on the rate of oxidation.

(c) On the effect of the size of coal dust particles on the rate of oxidation.

(d) On the effect of temperature on the rate of oxidation.

<sup>1</sup> "The Absorption of Oxygen by Coal," by T. F. Winmill. T. I. M. E. Vol. XLVI, 1914, pp. 559-591.

<sup>2</sup> Further reports have just appeared but it has been impossible to make use of them in the present work without delaying its publication. They are (a) "The Absorption of Oxygen by Coal" (Parts 2-6) by T. F. Winmill and J. Ivon Graham, Tr. Inst. Min. Engrs. Vol. XLVIII, 1915, pp. 503-49; (b) "The Absorption of Oxygen by Coal" (Part 7) by J. Ivon Graham. Tr. Inst. Min. Engrs. Vol. XLIX, 1915, pp. 35-43.

The methods used were as follows: a vessel containing coal was immersed in a bath of constant temperature and a steady stream of air passed through the coal mass, particular care being taken to ensure that the air did not find its way through definite channels. Pure air was obtained from a pipe passing through the wall of the laboratory into the outside atmosphere, and was drawn through the coal dust by a water aspirator, the rate of flow of the air being measured by the rate of flow of water from the aspirator. The air-stream issuing from the coal was analysed at intervals by means of a Haldane gas analysis apparatus. These analyses gave the percentages of oxygen, carbon dioxide, combustible gas and nitrogen in the sample; and the amount of oxygen absorbed was calculated by a method which took into account the dilution produced by the combustible gas and the carbon dioxide taken up from the coal, and allowed for all changes in the temperature and barometric pressure.

Six kinds of coal from the Barnsley seam near Doncaster<sup>1</sup> were tested as follows:—

Hard coal, Soft coal, Cannel coal, Jacks, Shale, and Mother-of-coal.

A portion of each was ground to pass through a 200-mesh sieve and was tested at 30°C in the apparatus above described. Further portions of the hard coal in coarser fragments were similarly tested to determine the difference in rate of absorption due to size.

Further portions of the 200-mesh "Hard" coal were similarly tested at 40°-50° and 60°C to determine the effect of elevated temperatures.

The results of the tests are set forth in Fig. 22 and Tables XXIX to XL, pp. 88-99.

<sup>1</sup> The paper states that the samples "have all been taken from a mine working the Barnsley seam, which is liable to spontaneous combustion." The coal oxidized so readily that fresh coal was required for the experiments, and "the average interval from the winning of the coal to the time when it was ground and in the experimental vessel has been about two hours." The sample was always selected from a "rapidly advancing face." The name of the mine is not given, but as the laboratory was in Doncaster the above statement makes it clear that the samples came from that immediate locality.

TABLE XXIX (A).

Hard Coal, Weight 150 grammes, passing through a 200-mesh sieve;  
Temperature 30°.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	993	18·16	0·10	0·64	1·75	20·86
2.....	984	18·88	0·07	0·45	3·75	15·28
3.....	437	18·04	0·06	0·43	7·75	9·78
4.....	423	18·64	0·08	0·28	11·75	7·51
5.....	398	18·99	0·07	0·21	16·25	5·99
6.....	351	19·14	0·07	0·14	25·00	4·92
7.....	325	19·56	0·05	0·08	36·00	3·51
8.....	290	19·47	0·09	0·10	44·00	3·35
9.....	294	19·47	0·08	0·09	47·00	3·26
10.....	276	19·51	0·08	0·05	52·25	3·08
11.....	248	19·60	0·08	0·00	64·25	2·60
12.....	554	20·40	0·05	—	71·00	2·34
13.....	236	19·84	0·05	—	87·75	2·02
14.....	234	20·00	0·07	—	112·50	1·72
15.....	286	20·22	0·06	—	139·00	1·62
16.....	286	20·25	0·07	—	161·00	1·53

TABLE XXIX (B.)

**Hard Coal.** Weight 136 grammes, passing through a 200-mesh sieve;  
 Temperature, 30° C. The intake air contains 8.28 per cent of  
 oxygen<sup>1</sup>.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	974	6.09	0.08	1.10	1.75	14.87
2.....	882	6.96	0.05	0.35	3.75	8.62
3.....	355	6.11	0.10	0.30	7.75	5.79
4.....	351	6.52	0.09	0.12	11.75	4.65
5.....	329	6.66	0.11	0.17	16.25	4.02
6.....	311	6.84	0.13	0.12	25.0	3.35
7.....	321	7.17	0.17	—	36.0	2.69

<sup>1</sup> This special test was run to determine the effect of exposure to air which had already been deprived of the chief part of its oxygen.

TABLE XXX.

Soft Coal. Weight of Coal, 150 grammes, passing through a 200-mesh sieve; Temperature, 30° C.

(Winmill.)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	474	15.09	0.16	2.04	2.0	21.71
2.....	490	17.10	0.11	1.11	5.5	14.36
3.....	487	17.99	0.10	0.45	9.75	11.21
4.....	474	18.47	0.09	0.34	13.75	8.96
5.....	380	18.55	0.10	0.33	18.0	7.09
6.....	280	18.49	0.10	0.37	24.0	5.36
7.....	226	18.23	0.40	0.22	30.0	4.72
8.....	500	19.93	0.08	0.10	43.0	3.89
9.....	492	19.95	0.08	0.16	53.0	3.70
10.....	480	20.17	0.07	0.06	66.0	2.86
11.....	470	20.24	0.06	0.03	78.0	2.57
12.....	465	20.22	0.07	0.00	90.0	2.62
13.....	461	20.35	0.06	—	101.0	2.15
14.....	435	20.37	0.08	—	114.0	1.96
15.....	187	19.61	0.10	—	143.75	1.94
16.....	168	19.80	0.11	—	160.75	1.49

TABLE XXXI.

Cannel Coal. Weight of coal, 150 grammes, passing through a 200-mesh sieve; Temperature 30° C.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal. per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	925	17.96	0.14	0.98	1.25	20.34
2.....	901	19.26	0.06	0.53	4.25	11.88
3.....	901	19.78	0.05	0.27	8.00	7.74
4.....	480	19.76	0.07	0.12	20.75	4.31
5.....	476	19.73	0.06	0.12	25.25	4.35
6.....	319	19.16	0.09	0.47	32.50	4.11
7.....	299	19.87	0.07	0.68	45.25	2.20
8.....	289	19.87	0.08	0.05	56.75	2.35
9.....	300	20.09	0.05	0.00	72.00	2.02
10.....	295	20.21	0.06	—	94.00	1.69
11.....	274	20.29	0.05	—	117.50	1.38
12.....	276	20.35	0.05	—	142.75	1.26

TABLE XXXII.

**Jacks.** Weight of dust, 150 grammes, passing through a 200-mesh sieve; Temperature, 30° C.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	487	15·85	0·14	2·15	2·00	18·44
2.....	480	18·02	0·07	0·90	5·50	10·52
3.....	474	18·97	0·05	0·48	9·75	7·16
4.....	470	19·32	0·05	0·29	13·75	5·88
5.....	470	19·56	0·06	0·25	18·00	4·67
6.....	474	19·80	0·07	0·23	24·00	4·14
7.....	355	19·63	0·06	0·20	30·00	3·61
8.....	500	20·13	0·03	0·18	43·00	3·04
9.....	488	20·24	0·04	0·14	53·00	2·59
10.....	480	20·42	0·05	0·10	66·00	1·90
11.....	475	20·49	0·05	0·01	78·00	1·63
12.....	473	20·46	0·05	0·00	90·00	1·75
13.....	471	20·46	0·06	—	101·00	1·74
14.....	706	20·67	0·04	—	114·00	1·47
15.....	212	20·06	0·05	—	143·75	1·45
16.....	188	20·27	0·04	—	160·75	0·99

TABLE XXXIII.

Shale. Weight of shale, 158 grammes, passing through a 200-mesh sieve; Temperature, 30° C.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	900	20·03	0·08	0·36	1·75	5·54
2.....	889	20·39	0·04	0·17	4·50	3·34
3.....	526	20·37	0·06	0·05	9·75	2·13
4.....	204	20·13	0·04	0·00	25·25	1·26
5.....	194	20·42	0·04	—	48·75	0·76
6.....	181	20·47	0·04	—	71·25	0·64
7.....	166	20·55	0·04	—	96·00	0·50
8.....	181	20·61	0·04	—	119·00	0·42

TABLE XXXIV.

Mother-of-Coal. Weight of mother-of-coal, 120 grammes; Temperature, 30° C.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	511	20·05	0·17	0·56	2·00	3·82
2.....	506	20·36	0·08	0·18	9·75	2·65
3.....	500	20·42	0·09	0·05	13·75	2·47
4.....	500	20·42	0·07	0·10	18·00	2·42
5.....	436	20·44	0·09	0·10	30·00	2·16
6.....	500	20·55	0·10	0·11	43·00	1·71
7.....	479	20·65	0·08	0·00	90·00	1·30
8.....	219	20·37	0·15	—	144·25	1·18
9.....	217	20·47	0·12	—	160·75	0·96

TABLE XXXV.

Hard Coal.—Weight 250 grammes; coal dust passing through 10-mesh and remaining on 30-mesh. Temperature 30°C. The column headed “R” gives the percentage ratio of the oxygen absorption for the coarse dust to that for the fine dust. The figures for the latter are taken from Table XXIX A.

(Winmill)

R <sup>1</sup>	No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
%		c.c.	Per cent.	Per cent.	Per cent.		c.c.
—	1	250	6.80	0.20	46.50	1.50	(14)
72	2	909	18.15	0.08	4.72	5.75	8.24
69	3	392	17.19	0.04	4.58	10.50	5.49
75	4	380	18.40	0.05	1.95	21.50	3.92
70	5	373	18.79	0.05	1.30	26.25	3.33
75	6	373	19.14	0.03	1.10	32.50	2.84
74	7	227	18.51	0.07	0.86	44.25	2.44
73	8	221	18.74	0.06	0.89	53.25	2.12
70	9	207	19.10	0.05	0.54	68.50	1.65
74	10	195	19.31	0.05	0.37	93.00	1.41
72	11	165	19.29	0.06	0.32	118.75	1.23
72	12	94	18.74	0.07	0.41	164.75	0.94

<sup>1</sup>Mean value of R, 72 per cent.

TABLE XXXVI.

**Hard Coal.** Weight 200 grammes; coal dust passing through 30-mesh and remaining on 60-mesh. Temperature 30° C.

(Winmill)

R <sup>1</sup>	No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
%		c.c.	Per cent.	Per cent.	Per cent.		c.c.
—	1	250	9.28	0.12	44.00	1.50	
85	2	920	18.75	0.05	2.31	5.75	9.46
83	3	500	18.54	0.04	0.85	10.50	6.62
80	4	496	19.47	0.05	0.50	21.50	4.00
80	5	496	19.82	0.02	0.27	32.50	3.02
82	6	174	18.56	0.06	0.39	53.25	2.37
80	7	174	19.02	0.06	0.39	68.50	1.89
78	8	157	19.30	0.06	0.24	92.50	1.49
79	9	153	19.44	0.09	0.14	116.00	1.31
70	10	125	19.67	0.08	0.28	165.00	0.90

<sup>1</sup>Mean value of R, 80 per cent.

TABLE XXXVII.

**Hard Coal.** (Secondary oxidation<sup>1</sup>). Weight of coal, 150 grammes, passing through a 200-mesh sieve. Temperature 30° C.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	536	19.09	0.16	0.40	1.50	7.39
2.....	536	19.53	0.11	0.33	3.00	5.65
3.....	308	19.25	0.10	0.31	5.50	3.90
4.....	311	19.65	0.10	0.29	9.00	2.98
5.....	209	19.65	0.07	0.32	21.00	1.92
6.....	207	19.97	0.06	0.20	32.00	1.50

<sup>1</sup> The coal used in this experiment was a portion of the sample from Table XXXV which had already oxidized as coarse dust for 165 hours. It was then crushed through 200-mesh and re-treated as shown.

TABLE XXXVIII.

Hard Coal. Weight, 121·4 grammes, passing through a 200-mesh sieve. Temperature 40° C.<sup>1</sup>

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	1,017	16·36	0·09	1·48	1·00	43·80
2.....	1,014	17·80	0·08	0·83	2·00	29·93
3.....	1,014	19·02	0·04	0·23	4·00	18·85
4.....	990	19·59	0·03	0·12	7·00	13·00
5.....	524	19·12	0·05	0·09	12·00	9·32
6.....	280	18·35	0·05	0·16	20·00	7·07
7.....	260	18·49	0·09	0·18	24·00	6·20
8.....	261	18·56	0·10	0·21	27·50	6·02
9.....	251	18·78	0·10	0·17	32·25	5·24
10.....	250	18·95	0·05	0·15	36·00	4·82
11.....	233	19·16	0·05	0·17	47·50	4·03
12.....	214	19·24	0·08	0·16	54·00	3·50
13.....	217	19·76	0·10	0·17	70·25	3·04
14.....	204	19·74	0·03	0·10	82·25	2·38
15.....	209	19·74	0·08	0·09	94·50	2·40

<sup>1</sup> This and tests XXXIX and XL were in parallel to XXIX (A) but at higher temperatures.

TABLE XXXIX.

Hard Coal. Weight 150 grammes, passing through a 200-mesh sieve.  
Temperature 50° C.

(Winmill)

No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	1,260	13.20	0.13	1.91	1.00	74.65
2.....	1,260	15.69	0.12	0.97	2.00	50.69
3.....	1,260	17.63	0.12	0.43	4.00	31.92
4.....	779	17.58	0.11	0.27	6.50	20.30
5.....	853	18.50	0.09	0.13	10.00	16.15
6.....	375	17.21	0.14	0.19	19.50	10.89
7.....	268	16.59	0.22	0.23	26.00	9.07
8.....	268	17.49	0.15	0.20	32.50	7.20
9.....	264	18.27	0.13	0.16	46.50	5.46
10.....	392	19.31	0.13	0.21	55.00	4.84
11.....	187	18.11	0.20	0.25	74.00	4.06
12.....	181	18.52	0.19	0.10	92.25	3.62
13.....	173	18.80	0.21	0.10	123.50	2.88
14.....	159	18.93	0.19	0.09	140.50	2.48

TABLE XL.

Hard Coal. Weight 100 grammes, passing through a 200-mesh sieve;  
Temperature 60° C.

(Winmill)

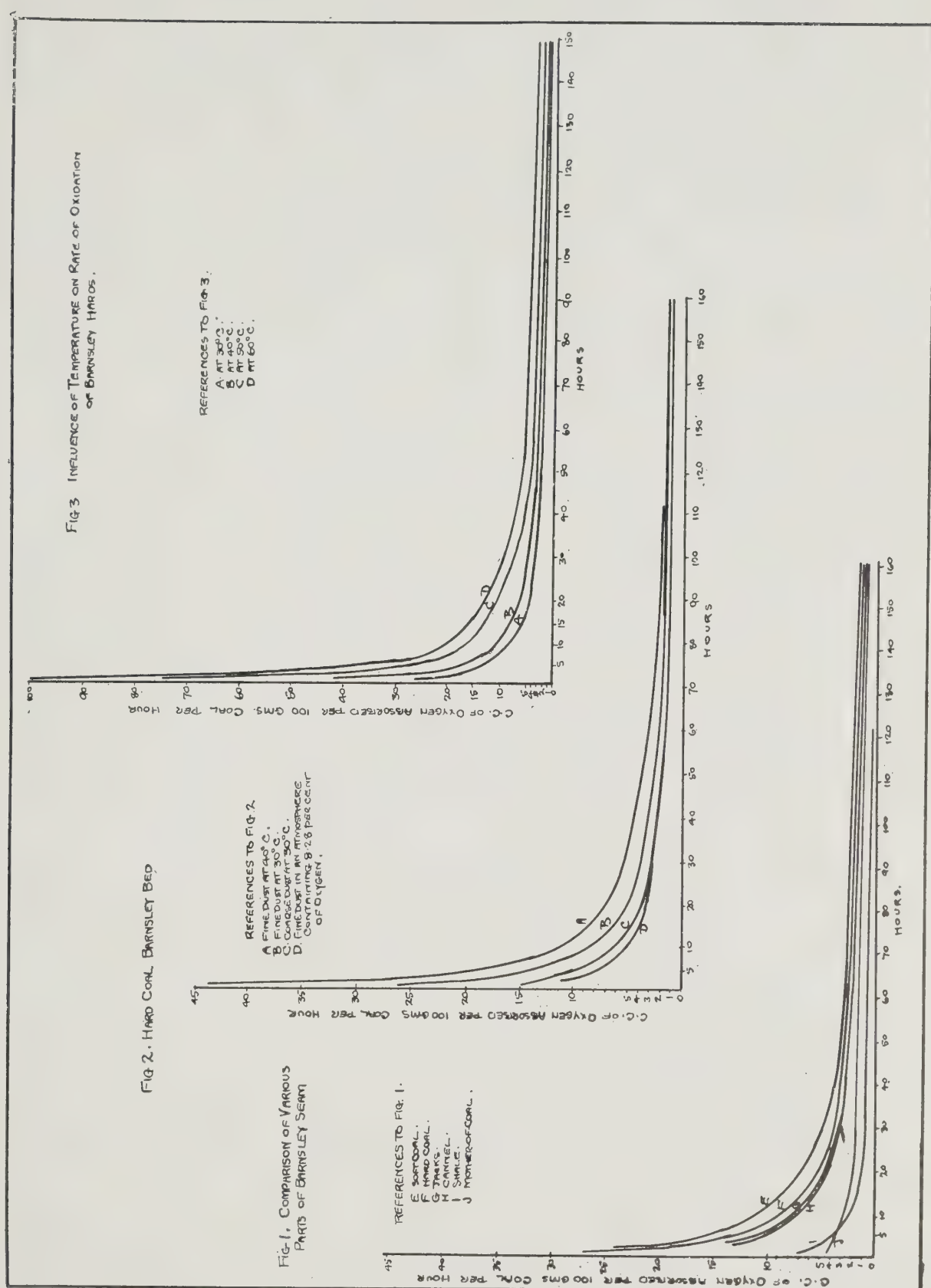
No. of sample.	Rate of flow of air per hour.	O <sub>2</sub>	CO <sub>2</sub>	Combust. gas.	Hours from start.	O <sub>2</sub> at N.T. & P. absorbed by 100 g. coal per hour.
	c.c.	Per cent.	Per cent.	Per cent.		c.c.
1.....	1,744	16.03	0.07	0.95	1.00	99.70
2.....	1,705	17.63	0.06	0.50	2.00	66.03
3.....	1,700	18.93	0.07	0.23	3.75	39.98
4.....	897	18.72	0.13	0.07	8.25	22.16
5.....	809	19.18	0.08	0.05	13.00	16.88
6.....	302	18.34	0.18	0.10	34.00	9.29
7.....	302	18.46	0.18	0.08	36.00	8.89
8.....	306	18.96	0.19	0.06	50.00	7.13
9.....	302	18.97	0.17	0.06	54.00	7.01
10.....	300	19.25	0.16	0.05	75.00	5.97
11.....	197	18.75	0.24	0.04	99.00	5.08
12.....	141	18.14	0.30	0.04	123.00	4.65
13.....	201	19.31	0.27	0.03	148.00	3.79
14.....	217	19.65	0.19	0.00	172.00	3.24
15.....	189	19.96	0.16	—	288.00	2.14

The general conclusions to be drawn from Winmill's results are as follows:—

(a) In the coals of the Barnsley seam, very rapid oxidation takes place in the first few hours in freshly got coal, and this is followed by a much slower absorption which persists for a long time. The great similarity of results for the different coals is noteworthy.

The absorption curves, Fig. 22, for the different coals are very close together for the most part and show that there is very little difference in the rate of oxidation. The amount of oxygen absorbed is roughly proportional to the content of carbonaceous matter in each case.

Winmill gives a mathematical analysis of these curves to show that each represents with a fair degree of accuracy the sum of two chemical reactions obeying definite equations. He states that his tests while not



(Redrawn from Winnill.)

Fig. 22. Rate of oxidation of coal under various conditions.

showing that pyrite is not a contributory factor to spontaneous combustion, point to the fact that heating can occur in the absence of oxidizable pyrite.

(b) Certain combustible gases—principally methane—are given off by the coal during oxidation, the total quantities per 100 grammes of each substance being as follows:—

Hard coal.....	37 c.c.
Soft coal.....	80 c.c.
Cannel coal.....	70 c.c.
Jacks.....	70 c.c.
Shale.....	12 c.c.
Mother-of-coal.....	30 c.c.

These quantities are of course exclusive of those lost during the grinding, which certainly far exceed those tabulated above as can be seen from the tables for coarse dust. (Tables XXXV and XXXVI).

(c) That a reduction of the oxygen of the intake air appreciably reduces the rate of oxidation is shown by Tables XXIX, A and B, but the rate is still very considerable, and “a proposal to stop, at any rate the earlier stages of spontaneous combustion by a reduction short of almost total removal of the oxygen, would appear to have no basis in fact”.

(d) From Tables XXXV, XXXVI and XXXVII it is seen that the rate of oxidation is not proportional to the size of the particles probably because the coal is porous and the oxygen is able to penetrate more or less into the interior of each particle; but it is shown that “the total absorption is the same whether the dust is ground up very slowly and oxidized at the same time or whether it is ground up rapidly and then oxidized.”

(e) Conclusions are not drawn as to the effect of temperature on the rate of oxidation as the experiments have not proceeded far enough to warrant them. A series of curves are given, however, together with four tables showing the results obtained for temperatures—30°C, 40°C, 50°C and 60°C, Tables XXIX (A) and XXXVIII—XL and the curves Fig. 22. These show clearly that the rate of oxidation increases greatly with increase of temperature.

Lamplough's criticism of the experiments is perhaps worthy of note here. He says:—

The effect of fineness of dust is apparently inconsiderable when the temperature is constant, yet, in practice, with a partial retention of heat the effect would probably be of much greater importance.

He does not believe that the absorption curves can properly be interpreted as due to two chemical actions, as suggested by Winmill, for—

though many different equations could be constructed to fit a limited curve, they could not be assumed true for later periods of the reaction. The fact is that it is quite incorrect to attempt to apply velocity equations to such reactions. The laws governing the velocities of chemical actions refer only to reactions occurring in a homogeneous solution, and any attempt to apply these laws to so heterogeneous an action as the absorption of a

gas by so complex a substance as coal dust is fallacious. This is further shown by the fact, that the experiments show that a gradual rise in temperature gradually increases the total absorption although this is contrary to the laws governing chemical actions. Moreover the rate is not proportional to nor yet independent of the fineness of dust.

A study of the various tables shows that in all the experiments the rate of flow of air has been a variable quantity, being usually of larger velocity at the beginning of the experiment than at the end. A variable rate of flow would undoubtedly affect the oxygen content of the sample taken, and as this is not shown as corrected, it would appear probable that the absorption results shown are not the results of constant and similar conditions in all samples taken during each test. Moreover it has been the experience of the author that the rate of flow of gas plays a part in the temperature rise of the coal<sup>1</sup> and therefore very probably also in the absorption of oxygen by the coal. In experiments of this kind too much care cannot be taken to keep all conditions constant except that one which it is desired to study.

If Winmill had kept the flow of air constant throughout each test it is extremely probable that his curves would not show such similarity, especially in the later hours of the experiment, and that this should be the case seems only right. For example, Winmill says that the amount of oxygen absorbed is roughly proportional to the content of carbonaceous matter in each substance, and quotes the soft coal with 90% carbonaceous matter absorbing 830 c.c. of oxygen, and the Jacks with 75% absorbing 560 c.c., whereas the curves in Fig. 22, show that after the 70th hour the Jacks are absorbing an average of about 2 c.c. per hour, a result that hardly seems justifiable if we assume the above statement to be substantially correct.

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<sup>1</sup> See page 136 et seq.



## CHAPTER V.

## OXIDATION AT ELEVATED TEMPERATURES.

**Varrentrapp**<sup>1</sup> is quoted by Langley as having placed a quantity of pulverized coal in a closed vessel through which a current of air could be drawn. The vessel and air were brought to a temperature of 280°F and the air, after passing through the apparatus, was caused to bubble through "certain chemical solutions which have the property of retaining and rendering visible" carbon dioxide. The solutions showed that carbon dioxide was present in the air and it is stated that the combustion was so complete even at 280°F that the whole of the carbon in the coal oxidized inside of three months. Langley evidently considered the latter part of the statement exceptional and stated that he had never known of such extreme oxidation with American coals; and Richters criticized the first part of the experiment on the ground that the carbon dioxide may have been occluded in the coal before the experiment was started.

In the light of our present knowledge of the subject it is scarcely necessary to say that Langley's criticisms are more than justified. No ordinary coal oxidizes to the extent stated, and even Langley's much more moderate estimates were over rather than under the truth. The statements are, however, interesting as showing the opinions of very early experimenters.<sup>2</sup>

**Richters**<sup>3</sup> work, although done half a century ago, is of interest here, and a résumé is therefore given below. His conclusions in brief are that the volume of oxygen absorbed by freshly mined coal is to a certain extent dependent upon the hygroscopicity of the coal. He also thinks it probable that there is a "definite relation between the absorption of oxygen and the content of disposable hydrogen in coal", and he was able to prove that oxygen becomes chemically combined with the coal.

The quotations which follow are taken with few corrections from the translation by Wilson and Helms in the Report of the New South Wales Commission on Coal Cargoes, pp. 80-2 (1897.)

"We know that coal always absorbs oxygen quickly at elevated temperatures and slowly at ordinary temperatures. The chemical and other changes which the combustible substance of coal undergoes under the first condition have already been established by me. On the other hand, at ordinary temperatures the absorption of oxygen is, in so far, a matter which in no way assists us in understanding the chemical changes which are consequent upon it. Whether and how far the carbon or hydrogen is the cause of the oxidizing action

<sup>1</sup> See discussion of Pechin's paper, T. A. I. M. E. Vol. I, 1872, p. 285.

<sup>2</sup> Porter and Ovitz have recently experimented using 5 grammes of coal (80-100 mesh), in an electrically heated tube kept at definite temperatures. They passed a measured volume of dry air over the coal at a definite rate. The carbon dioxide evolved from the coal was found to be equal to only one-tenth of the volume of oxygen absorbed. (See International Congress of Appl. Chem. Vol. X, 1912, p. 265, Fig. p. 253. This matter is much more fully dealt with by Porter and Ralston in "A Study of the Oxidation of Coal", Tech. Paper No. 65, U. S. Bur. of Mines, Washington, 1914.

<sup>3</sup> Dinglers Poly. Journal. Vol. 195, 1870, pp. 315 and 449.

of the oxygen; whether the action of the latter is not essentially confined to the formation of carbon dioxide, which is then absorbed by the coal; and whether, further, the absorption is a chemical or more or less physical process, are all questions which are of the greatest interest for a critical examination of the phenomena of the weathering of coal. \* \* \*

"I shall offer several observations which appear to me to be of importance for throwing light upon the first of the questions propounded above. If we heat coal-dust to a temperature from  $180^{\circ}$  to  $200^{\circ}$  C., the weight at first increases rapidly in a very marked manner; carbon dioxide and water are then separated, and oxygen is taken up in greater proportion than is required for the oxidation of the carbon and hydrogen. After a certain time the oxygen absorption, and with it the alteration in weight, comes to an end. If we continue to heat the coal, at first there is a small diminution in weight, but after a while the weight, as well as the chemical composition of the coal, becomes constant, or rather, the variations which the coal undergoes are so small that in an experiment which was continued for six days a good chemical balance was unable to show any further variation. If we examine the constitution of coal which has been heated up to the point of maximum absorption of oxygen, we find that the oxygen and hydrogen are present approximately in the same proportions as in water. This interesting behaviour of coal brings to light two important phenomena. It shows firstly that the carbon of the coal is endowed with a very variable degree of oxidizability, and makes it, in the second place, probable that there is a perfectly definite relation between the absorption of oxygen and the content of disposable hydrogen in the coal, since with the vanishing of the latter the oxygen absorption comes to an end. The first circumstance agrees with the view which is generally taken by chemists that the carbon in coal exists in two different chemical forms. We may say that the coal is a mixture of pure carbon with obscure organic compounds containing carbon, hydrogen, oxygen and nitrogen. These carbon compounds are sometimes grouped together under the name of "bitumen". The rapid evolution of carbon dioxide which takes place when the coal is first heated may be attributed to the oxidation of the carbon of the bituminous constituents, while the relatively much smaller evolution of carbon dioxide which succeeds, may be attributed to the oxidation of the more difficultly oxidizable carbon."

Richters thinks this view may be supported by Saussure's observations of the similar phenomena occurring during the absorption of oxygen by wood, charcoal, etc., and by the researches of Liebig on lignite and true coal.

"On the ground of these observations we come to the following conclusions, which are of importance for our knowledge of the behaviour of coal in the presence of oxygen:—

(1) "The peculiarity of coal, when heated to  $190^{\circ}$ C., in taking up oxygen, depends almost entirely on the fact that the coal contains disposable hydrogen. This is oxidized in presence of a certain quantity of carbon. On the one hand water is formed, while on the other oxygen takes its place directly in the composition of the coal; (2) the carbon of coal when exposed to oxygen at a temperature of  $190^{\circ}$ C, behaves in a totally different manner, in that the smaller part—5 to 6 per cent only—of the whole weight combines, forming carbon dioxide. The remainder is only slightly or not at all altered by oxygen at that temperature."

"It is to be noted that both these conclusions refer exclusively to the oxidation of coal at elevated temperatures; since, however, we observed precisely the same relations existing during the oxidation of coal at ordinary temperatures, there is very strong evidence that the processes of oxidation at both high and low temperatures are essentially similar."

"During the heating of coal, as well as at ordinary temperatures, oxygen is absorbed. That, in the latter case the absorption of oxygen is related to the disposable hydrogen in the same manner as in the first case, is made clear by the behaviour of wood and its decomposition products."

"It is also clear that the content of disposable hydrogen is diminished when coal is exposed to air in a manner similar to that in which it is diminished when the coal is heated.

It may be shown with certainty that carbon dioxide is formed at ordinary temperatures in the same way as it is formed at higher temperatures, and, in both cases, when the more easily oxidized portions of the carbon come to an end, the oxygen absorption reaches its maximum.

The assumption that the more difficultly oxidizable carbon behaves with regard to oxygen at low temperatures differently to the way in which it behaves at high temperatures, would contradict all experience.

It cannot be maintained that the absorption of oxygen at ordinary temperatures is merely a physical process, still the surface action of the coal is perhaps not to be neglected.

We must distinguish between the tendency which the coal has to absorb oxygen and the intensity with which oxygen is at first actually absorbed. It appears to be not improbable that in the earlier stages the absorption of oxygen is a purely mechanical process, and that this precedes the chemical combination.

The quantity of hygroscopic water which coal actually takes up when exposed to air saturated with water vapour at 15°C. was determined for more than 100 samples by heating them to 100°C. until the weights became constant. The percentage of hygroscopic water thus liberated varied from 2 to 7.5, but the power of the coal for condensing hygroscopic moisture did not appear to be related to its structure in any determinate manner. The condensing of hygroscopic water on the surface of the coal, however, shows very clearly the condensing power possessed by coal. If we examine the quantity of oxygen which different coals absorb from the air, under similar circumstances, we find that there is a very close connection between this quantity and the power of the coal for condensing moisture. In order, however, to obtain complete and decisive experimental results in this connection it is necessary that care should be exercised in selecting coal which has been freshly obtained, and has not been lying in contact with atmospheric air.

Fresh coal, after it has been pounded, ground, and sieved, gives an apparently dry powder, although this is saturated with moisture.

\* \* \* \* \*

"The absorption of oxygen by the freshly-prepared coal begins at once and goes on rapidly. The volume of the absorbed gases, though not proportional to the surface action of the coal as indicated by its hygroscopicity, are, nevertheless, very dependent upon it. I intend to make a further communication in greater detail as to the results of this experiment, and will, therefore, confine myself in this place to the statement of the quantity of oxygen absorbed during the first twenty-four hours by 20 grammes of different samples of coal, a quantity which varies between 2 and 9 c.c. I may, however, mention certain circumstances which appear to me to strengthen my position in considering that at first the absorption of oxygen is chiefly mechanical."

(The observation on which reliance is placed appears to be that the oxygen absorption is at first very much more rapid than is the case later on.)

Richters then notes that Varrentrapp has shown that when coal is exposed at ordinary temperatures to a stream of air, carbon dioxide is formed. He suggests that carbon dioxide may have been originally condensed upon the surface of the coal, and that it is gradually removed by the stream of air, its place being taken to some extent by oxygen. In order to clear up this point certain special experiments were made which rendered it probable that the continued absorption of oxygen is not to be explained by assuming that it merely takes the place of carbon dioxide condensed upon the surface of the coal.

"Coal absorbs carbon dioxide with the greatest readiness. The volume of this gas which is taken up in a given time is often greater than three times the volume of oxygen which could be taken up. Samples of coal whose absorptive power for oxygen has almost vanished, so much so that 20 grammes will only take up about 1 cubic centimetre of oxygen, will absorb in a few hours at least their own volume of carbon dioxide. If a sample of coal saturated with carbon dioxide is brought into contact with atmospheric air, we find at first an increment of volume as if the carbon dioxide is given off. Soon, however, the volume again begins to diminish. If, at the same time, a small bulb containing caustic potash is introduced in the absorption tube, or if the sides of the latter are moistened with a solution of caustic potash, the absorption of the oxygen goes on very quickly, as does the separation of the carbon dioxide which, of course, forms a compound with the caustic potash. If we leave samples of coal saturated with carbon dioxide for thirty-six hours under the receiver of an air pump exhausted to 2 inches of quicksilver, the greater portion, but not all, of the absorbed carbon dioxide is given off. If a sample of coal which has been so treated is then saturated with moisture and again put into an absorption tube it begins to take up oxygen with the same avidity as when it was freshly prepared, and this whether any potash is present or not. If potash is present, however, we soon discover that a certain quantity of carbon dioxide has been liberated, which shows that the absorption of oxygen is at first accompanied by a separation of carbon dioxide, and that this carbon dioxide will again be taken up by the coal in the absence of any other substance capable of absorbing it."

"If coal which has been saturated with carbon dioxide is boiled for half-an-hour in water and is then air-dried, so that it remains saturated with hygroscopic moisture, it is found to have recovered its original absorptive properties."

"Coal which has been exposed for a long time to the air until it has lost its power of absorbing oxygen behaves in a completely different manner when the foregoing experiments are performed upon it. For instance, when exposed under the receiver of an air-pump it does not by any means recover its original power of absorption, though this power is still partly restored by boiling out with water. Carbon dioxide is either not absorbed at all by such coal or in only very small proportions."

The observations show that the small absorptive power of coal which has been lying for a long time in the air does not depend upon a condensation of carbon dioxide upon its surface, and other conclusions may also be drawn. Amongst these may be mentioned the following:—

"We may now explain the experiments of Varrentrapp. The coal which has lost its power of absorbing oxygen may, nevertheless, absorb large quantities of carbon dioxide, and, on the other hand, when this coal which contains carbon dioxide begins to take up oxygen the process is accompanied by a separation of carbon dioxide. Now, this process is not very noticeable when the experiment is carried out in closed tubes, but it becomes noticeable when the experiment is performed by Varrentrapp's methods."

In considering the influence of heat on the process of oxidation,

I have formerly shown that a rise of temperature is the most important determining circumstance of the process of oxidation. It is not, however, necessary to use a temperature which lies far above 100°C., though the higher the temperature the greater the acceleration of the process. In pursuance of these experiments I heated coal for fourteen days on the water bath at from 70° to 80° C. The first sample of coal increased in weight during this process by 1.01 per cent, the second sample by 0.2 per cent, and the third by 0.35 per cent. (The constitution of these three samples of coal before and after fourteen days heating is given by three tables of analyses accompanying Richters' paper). In all cases there was a diminution in the carbon and hydrogen content and an increase in the oxygen content, exactly as in ordinary weathering. The coking power of sample (1) was diminished from 1.4 to 1.1; of sample (2) from 2 to 1.6; sample (3) was a so-called "sandkohle" which does not give coke. The quantity of the coke did not appreciably change, and the specific gravity certainly did not. The heating power of sample (1) fell by 2.62 per cent; of sample (2) by 3.61 per cent; and of sample (3) by 3 per cent. \* \* \* \* \*

"Samples of coal employed in these researches had remained for a long time in loosely stoppered bottles, so that the absorption of oxygen at ordinary temperatures only took place very slowly. As a control, check analyses of the unheated coals were made after they had suffered fourteen days longer exposure. The fact that during this time the composition of the samples did not undergo any variation, shows clearly that the increase in oxygen and loss in carbon and hydrogen is really to be attributed to the higher temperatures to which the coals were exposed."

"There appears to be a certain contradiction between the observation that oxidation goes on more rapidly at upper temperatures, and our thesis that oxidation follows a preliminary surface condensation of oxygen. This apparent contradiction is, in my opinion, easily cleared up if we distinguish clearly between oxidation and mere absorption. The first goes on more rapidly at elevated temperatures, the latter at lower temperatures. If the coal has been saturated with oxygen at lower temperatures, the condensed gas combines only gradually with the substance of the coal, and only in proportion as the latter process advances can new quantities of gas be taken up. When, however, coal which is saturated with oxygen is heated, a portion of the gas is evaporated; but the greater part enters into chemical combination, and does so more rapidly as the temperature is higher. The surface action, however, neither undergoes any appreciable change, nor produces any result at all comparable with the chemical action."

In studying the influence of moisture on the absorption and on the oxidation of coal,

"The greater number of technicologists are of opinion that moisture has an important aiding action in the weathering of coal. (Thompson's researches are mentioned in connexion with this point). That moisture may, under certain circumstances, aid the oxidation of coal is not to be denied; but the action of moisture is very complicated, and is influenced by various circumstances, and is not so generally prejudicial as Thompson's observations would lead us to imagine. I will communicate the result of a few experiments made upon this subject."

"If we take two tubes, and into one of them introduce air-dried and into the other moist coal, both being freshly won, the first absorbs oxygen much more rapidly than the second. If, in addition, small bulbs containing fused chloride of calcium are introduced alongside of the dry sample of coal so that the coal gets gradually drier, the intensity of the absorption of oxygen becomes greater. The same is the case if the coal has been dried for a day over sulphuric acid, although during this process a very considerable quantity of oxygen must certainly have been taken up."

"If instead of fresh coal we take two samples of coal with different surface properties, both of which have been exposed to the air for a long time and which have lost their power of absorption to a great extent, and expose them to the drying action of sulphuric acid, both of them recover to some extent their absorptive power. That coal with the greater surface action recovers most completely."

"If we dry coal at 100°C., and cool it in a desiccator and place it in an absorption tube, it is found to absorb gas with extraordinary rapidity. This gas consists in part of nitrogen (from 12 to 21 per cent., from the mean of many experiments). Coal which has been dried at ordinary temperatures also takes up nitrogen, but in smaller percentages, at the same time as it absorbs oxygen."

"All these experiments indicate only a relative increment of the power of absorption by the removal of moisture, and establish in so far the view which has been taken in the former work as to the nature of surface action. They also show that a dry coal will take up a larger volume of gases than one which is merely air dried, before the absorptive power of the two samples sinks to the same level."

These researches, however, still leave unanswered the question as to how far the moisture is disadvantageous for the chemical action of the oxygen upon the coal. I had hoped to be able to give a definite answer to this question, but I have not succeeded in coming to a positive decision. \* \* \* \* \*

"These observations would seem to support the assumption that water assists the process of oxidation; but on repeating the experiment several times—that is, first wetting and then drying the coal by means of chloride of calcium—we finally reach a state at which no further increment of absorptive power is to be observed."

"We may, however, approach the question by inquiring whether the action of water on the decomposition of coal is not to be attributed to the consequences of secondary action. Many coals contain pyrites which is only oxidizable in the presence of moisture. This process is undoubtedly of importance, even if it is regarded only as indirectly introducing active material for the oxidation of the coal."

The well-known action of pyrites in breaking up the coal and exposing fresh surfaces is then described. The question as to whether ferrous oxide can act as a carrier of oxygen to the coal is discussed, and it is considered that the small quantity of this substance which is present can only account for a very small part of the action.

### General average results from all the coals tested, in dust

Time of exposure (hours)

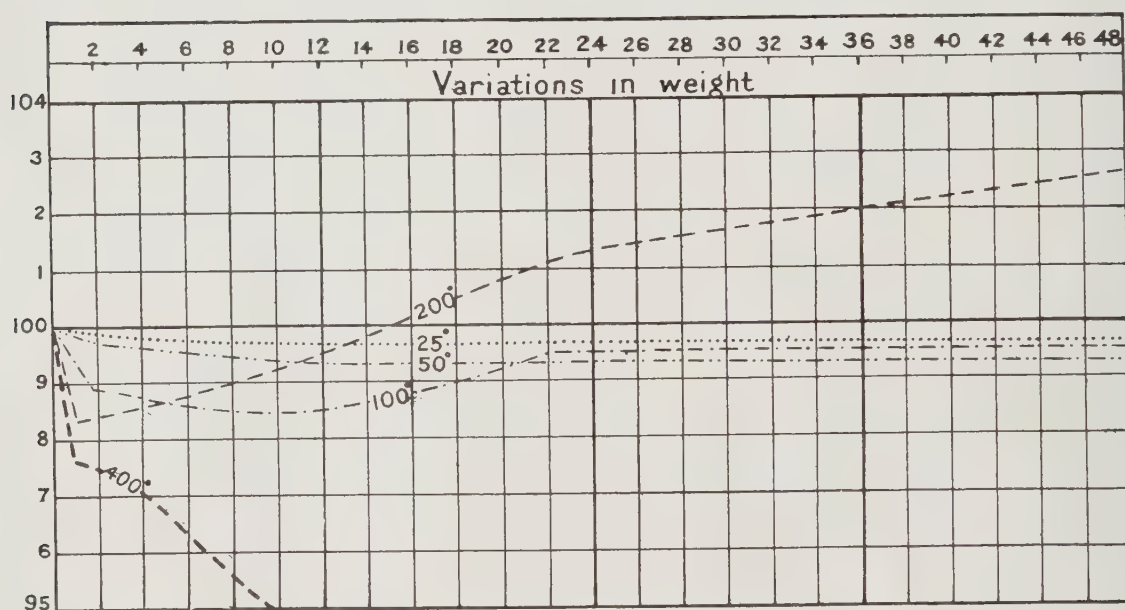


FIG. 23.

(Redrawn from Fayol.)

Fayol<sup>1</sup> took samples of a large number of coals, varying from anthracites to lignites, and heated them in loosely covered porcelain crucibles in ovens maintained at temperatures ranging from 25° to 430°C. Air was slowly passed through the ovens and the crucibles were weighed from time to time to determine the variations in weight. Twenty gramme samples were taken and for each coal four similar crucibles were used—two contained powdered coal and two lump. Each time the crucibles were weighed the coal was stirred with an iron spatula to allow penetration of air. The results obtained were plotted by Fayol in a series of very interesting curves

<sup>1</sup> Études sur l'altération de la houille exposée à l'air, 1879.

which are too numerous for reproduction here. His two final summary curves, giving the mean results for all of the samples tested, are reproduced in Figs. 23, and 24. (See also pages 26 and 52-3.)

Parr and Kressmann<sup>1</sup> draw attention to the rapidity of oxidation of certain hydrocarbon compounds at temperatures in excess of 120°C. and to the extremely exothermic nature of this reaction when once started; they point out the danger of any influence existing near coal which may tend to increase the velocity of this reaction which is almost negligible at ordinary temperatures.

### General average results from all the coals tested, in dust Time of exposure (days)

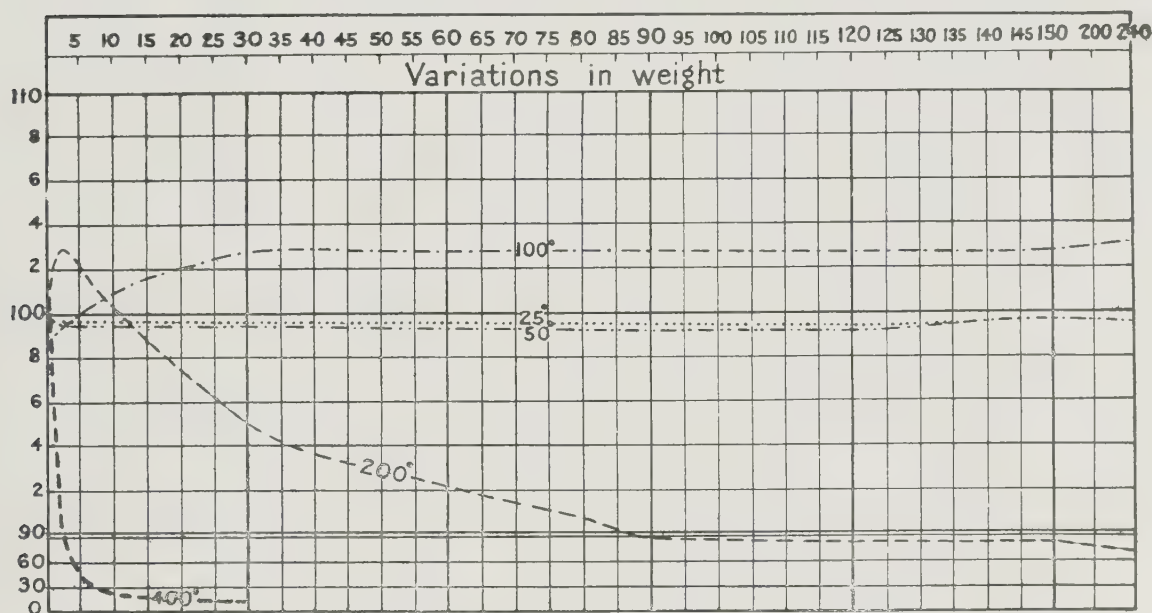


FIG. 24.

(Redrawn from Fayol.)

The following are among the conclusions arrived at by Parr and Kressmann<sup>1</sup> after making a number of experiments on spontaneous combustion of coal.

1. "A number of oxidation processes are involved, which are more or less distinct in character, some being relatively slow and moderate in form, while others are rapid and vigorous in their action."

2. "In general it may be said that for a given coal a point exists, as indicated by the temperature, below which oxidation is not ultimately destructive. The continuance of this point is dependent upon certain accessory conditions; if these conditions are withdrawn, the oxidation ceases. On the other hand above this critical point, which is best indicated by temperature, oxidation is ultimately destructive and is characterized by the fact that it does not depend for its continuance upon external conditions, but is self-propelling or autogenous."

3. "The point of autogenous oxidation, while varying for different conditions may be indicated by temperatures of the mass ranging from 140° to 160°C in an atmosphere of

<sup>1</sup> Univ. of Illinois, Eng. Expt. Station. Bulletin No. 46, 1910.

oxygen or approximately between 200° to 275°C in oxygen diluted with nitrogen, as in air, depending to a great extent upon the fineness of division. The phenomenon of fire or actual kindling does not occur until a much higher temperature is reached, usually beyond 350°C."

4. "The temperature at which autogenous oxidation begins is the sum of numerous temperature components, each one of which either because of its own contribution to the total heat quantity or because of its function as a stimulus for chemical activities, must be looked upon as a dangerous factor, tending directly to the ultimate result of active combustion throughout the mass."

An enumeration of the more important factors in oxidation is then given together with a short discussion of each. These are, in brief:—

a. External sources of heat.—Oxidation, especially of the lower form is greatly accelerated by; and in some cases dependent upon, external or physical sources of heat such as climatic or seasonal temperature, the heat of the sun, etc., contact with steam pipes, and heat of impact or pressure due to depth of piling or method of loading or unloading.

b. Fineness of division.—Coal in a state of fine division exposes a relatively very large surface area to oxidation. It especially facilitates the initial form of oxidation described under c.

c. Easily oxidizable compounds.—A first or initial stage of oxidation exists in bituminous coals which does not result in the formation of carbon dioxide. There are present in coals of this type, unsaturated compounds, which have a marked avidity for oxygen at ordinary temperatures, the products being humic acid or other fixed constituents of the coal texture.

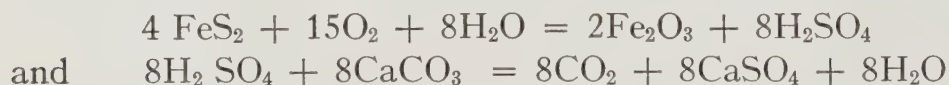
d and e. Pyrites and moisture.—These have already been dealt with. The oxidation of pyrite may be considered the second stage in the oxidation of coal.

f. The oxidation of Carbon and Hydrogen.—A third stage of oxidation of the carbonaceous material exists by reason of the tendency of certain of the hydrocarbon compounds of coal to oxidize with the formation of carbon dioxide and water at temperatures in excess of 120° to 140°. This oxidation does not take place appreciably at ordinary temperatures. It is, however, a dangerous stage in the process of oxidation as the large amount of heat given out may quickly raise the temperature of the mass to the critical temperature. Any initial process which results in raising the initial temperature 50°C above the ordinary temperature would, in all probability, have enough material of the sort involved in such action to continue the action until the temperature had been raised another 50° and then this third type of oxidation would begin.

g. The fourth stage of oxidation may be indicated as occurring at temperatures above 200° to 275° and differs from the previous stages in that it is autogenous. Activity in this stage is further accelerated by the beginning of exothermic decomposition of the coal itself. Ignition begins at a still higher temperature, usually above 300° to 400°C.

**Haldane and Meachem**<sup>1</sup> are of the opinion that the carbon dioxide evolved when coal is oxidized is not due to the combination of oxygen with the carbon of the coal, but that it is due to decomposition of carbonates by means of sulphuric acid formed by oxidation of the pyrite.

The chemical reactions which take place when pyrite is oxidized are:—



<sup>1</sup>T I. M. E. Vol. 16, 1898, p. 457.

"It will be seen that for every 15 volumes of oxygen which disappear in this reaction 8 volumes of carbonic acid are liberated. It will be found on calculation that in air passing over such material, the ratio of diminution in oxygen and increase in carbonic acid will be 1:74. This corresponds very closely to the average ratio observed in the air from old workings by Messrs. Haldane and Atkinson, and in the return air from most pits."

The reasons given to support this theory are numerous. Among them are the fact that some pyrites in coal does oxidize when exposed to air, the fact that sulphuric acid is thus formed and that this sulphuric acid will attack any carbonates with which it comes in contact, and the fact that the proportion of carbon dioxide thus formed is about sufficient to account for what is actually found to be liberated. This theory also explains how there can be absorption of oxygen without evolution of carbon dioxide. Against this theory, however, we have a great mass of recent observation and opinion as already set forth on pages 31 to 43.

A recent paper by **Lamplough and Hill**<sup>1</sup> on the slow combustion of coal dust describes some ingenious experimental work which was well carried out. Their experiments and results, in so far as they bear on the matter under discussion, may be summarized as follows.

The evolution of heat and the absorption of oxygen were measured by placing a weighed quantity of coal<sup>2</sup> in a pint Dewar vessel (vacuum flask) filled with oxygen and fitted with a sensitive electric thermometer consisting of a four junction copper constantan thermopile inserted in the coal. The flask was connected with an oxygen reservoir of about double its capacity, and provision was made for automatically registering the gas pressure continuously throughout the experiment, so that the quantity of oxygen absorbed from time to time could be calculated. The whole absorption system was enclosed in a water thermostat which could be kept approximately constant at any desired temperature, and provision was also made to replenish the supply of oxygen from time to time from an external source, the quantity added being calculated from the changes in pressure, etc.

The gases in the apparatus were measured and analysed at the beginning and end of each experiment to determine the amount of carbon dioxide produced and methane evolved.

Lamplough and Hill experimented with ten samples all told, six of them being from different parts of the Barnsley seam and one from the "Bullhurst" seam; the eighth coal was an anthracite. The additional samples were: a Barnsley top soft carrying 43% of pyrites and a sample of pure lump pyrites collected from the rubbish in a coal yard. The results of their experiments, which were conducted at 45°, are summarized in the following tables and conclusions copied from their paper.

<sup>1</sup> Trans. Inst. Min. Engrs. Vol. 45, 1913, pp. 629-657.

<sup>2</sup> The coal was ground to pass through a 30 mesh sieve "and 300 grammes were used in most of the experiments." In the earlier experiments so much marsh gas was given off that very little oxygen could enter, and thereafter the coal previous to its introduction into the apparatus, was heated in a florence flask in vacuo to 47° for a day. The gas evolved was measured and allowed for by analysis.

TABLE XLI.  
Summary of Results  
(Lamplough and Hill)

(1)	(2)	(3)	(4)	(5)	(6)
Description of coal.	Ash. %	Iron. %	Oxygen absorbed <sup>1</sup> . c.c. dry at normal T. & P.	Heat evolved <sup>1</sup> . Calories.	Calories evolved per cubic centi- metre of oxygen absorbed.
Top softs, containing 43 per cent of pyrites <sup>2</sup> .....	40	20.2	321	1,158	3.6
Anthracite.....	—	—	132	495	3.6
Top coal.....	1.1	0.1	459	1,275	2.8
Bullhurst.....	3.2	1.2	60	234	3.8
Hard coal No. 1.....	6.0	0.1	195	705	3.6
Top softs:—					
First part.....	2.8	0.8	534	1,684	3.2
Second part.....	—	—	1,041	3,089	3.0
Hard coal No. 2.....	4.0	0.1	1,110	3,196	2.9
Slack.....	3.2	1.4	31	115	3.7
"Iron pyrites" <sup>2</sup> from coal.....	—	—	240	800	3.3

<sup>1</sup> The paper states that the amount of coal used in "most of" the experiments was 300 grammes, and it is probable that the figures in these two columns refer to this quantity in all cases, but unfortunately the paper is not specific on this point. It is unfortunate also that the several experiments were not of equal length although the time averaged about 12 hours.

<sup>2</sup> The word "pyrites" has been used throughout to designate the sulphide  $\text{FeS}_2$ , without prejudice as to its nature. From its crystalline form it was evident that some of the material used in the last experiment was pyrites and not marcasite."

TABLE XLII.  
Summary of Results  
(Lamplough and Hill)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Description of coal.	Oxygen absorbed.	Carbon dioxide evolved.	Carbon dioxide evolved per 100 cubic centi- metres of oxygen absorbed.	Initial rate of absorption per hour.	Final rate of absorption per hour.	Final temper- ature.
	c c.	c c.	c c.	c c.	c.c.	°C.
Top softs, contain- ing 43% of py- rites.....	321	118.0	37.0	54.0	55.0	51.2
Anthracite.....	132	0.0	0.0	59.0	32.0	49.4
Top coal.....	459	5.4	1.8	46.0	46.0	52.7
Bullhurst.....	60	0.4	0.6	11.2	7.7	47.2
Hard coal No. 1...	195	2.7	1.3	18.6	22.0	50.0
Top softs:—						
First part.....	534	3.6	0.7	186.0	—	—
Second part.....	1,041	20.8	2.0	—	189.0	66.4
Hard coal No. 2...	1,110	12.1	1.0	90.0	78.0	62.5
Slack.....	31	0.02	0.06	14.0	13.7	46.0
"Iron pyrites" from coal.....	240	102.0	43.0	475.0	—	—

"General conclusions:—(1) The heat which was evolved when coal-dust was heated in an atmosphere rich in oxygen was nearly proportional to the volume of oxygen absorbed, the mean value being 3.3 calories of heat produced during the oxidation brought about by the absorption of 1 cubic centimetre of oxygen.

(2) The production of heat may be attributed to two chemical changes, namely, the oxidation of iron pyrites and the oxidation of carbonaceous matter.

(3) The oxidation of carbonaceous matter in coals practically free from iron was not so rapid as in those containing much iron, but continued for a long time, comparatively little carbon dioxide being evolved, so that eventually there was considerable evolution of heat even in the absence of ventilation.

(4) The oxidation of iron pyrites picked from coal was at first very rapid, but soon almost ceased, because the flask became choked with carbon dioxide, which prevented further admission of oxygen. With conditions under which there is diffusion of air through the coal-dust, and when a considerable amount of iron pyrites is present, the oxidation of this mineral would possibly be the predominant factor in the spontaneous heating of such coal-dust.

(5) Oxidation of coal-dust takes place in contact with gas containing much less than the normal proportion of oxygen present in air.

(6) The oxidation of carbonaceous matter and the total changes occurring in pyrites during the absorption of a given volume of oxygen produce about the same amount of heat, so that the rate at which heat is given off in the oxidation of coal-dust due to either process may with surprising nearness be determined by the volume of oxygen absorbed."

Lampough and Hill's experiments are very interesting and their observations regarding pyrite (marcasite) are no doubt largely justified in the case of coals carrying considerable quantities of very finely divided pyritic material; but their conclusions go very far in view of the amount of work done and it would seem reasonable to offer the following criticisms.

Referring to the experiment with pyrites they say: "It was seen from the pressure curve that the greater part of the carbon dioxide was evolved after most of the oxygen absorption had taken place. It may be concluded from this that the carbon dioxide is produced as a result of a reaction brought about by the products of the oxidation of the pyrites." The above pyritic material was possibly free from carbonaceous matter, but unfortunately an analysis is not given either for carbonate or coaly matter and no microscopic examination was made. The large evolution of carbon dioxide from this material in the short period over which the experiment lasted might indicate long previous exposure or the presence of a considerable amount of carbonate. It may be also noted that the amount of carbon dioxide evolved from the various coals appears from the table to have no relation whatever to pyritic content.

Considering the experiments with "Top softs containing pyrites" and Top coal; if pyrites in coal has such a large effect in the generation of heat spontaneously how is it these two experiments are so similar: the one coal containing 43% and the other 0.2% pyrites. Both, however, contain similar carbonaceous matter differing only in proportion.

Reference to column 6, Table XLI would seem to justify Dr. Harger's remarks in discussion of the paper to the effect that it is inconceivable that "Top softs" and anthracite should give the same value of 3.6 cal. per c.c.

of oxygen absorbed, when the one evolves so much carbon dioxide and the other none at all. Harger further finds no evidence in the paper justifying conclusions Nos. 2 and 4.

Had the experiments been longer and all of equal duration much more useful information might have been obtained, as some of the coals would probably have eventually commenced to split off oxygen again as carbon dioxide.

In the cases where the experiment was stopped owing to accumulation of carbon dioxide, the suspension of a small vessel containing some carbon dioxide absorbent in the container with the coal might have been tried; this would perhaps have permitted longer experiments.

The chief weakness which appears in the method is this accumulation of carbon dioxide and methane in the vessel with the coal and the consequent lowering of the partial pressure of oxygen. The coal is therefore subjected to an atmosphere of rapidly changing composition. This difficulty was avoided in the method employed at McGill University, in October 1912, the coal being subjected to the influence of an atmosphere of constant composition and the products of combustion being continuously replaced by fresh gas, while the quantities of carbon dioxide and water vapour and hydrocarbons in the gas discharged were determined immediately after leaving the coal. Experiments may thus be continued for a considerable time so that any products indicating oxidation of pyrites or loss of carbon and hydrogen may be more easily detectable by analysis.

A final criticism is that no figures are given which make it possible to estimate the effect of errors in sampling in the several experiments. We have already seen that such errors usually exist and that their correction often increases the intelligibility of the results.

Winmill has just published<sup>1</sup> the results of some experiments on Barnsley "hard" coal at temperatures of 30°, 40°, 50° and 60°C. showing a very great increase in the rate of oxidation as the temperature rises. A description of these results and a series of tables will be found on pages 86-101 at the end of an abstract of his work, the main part of which was on the same coal at ordinary temperatures.

#### PORTER, BILLINGTON, AND CAMERON EXPERIMENTS.

Porter, Billington, and Cameron carried on a series of tests on the behaviour of coal in an atmosphere of oxygen at elevated temperatures at McGill University from 1912-14. Their work will now be set forth in considerable detail as it has not heretofore been published.

The investigation was undertaken by Dr. Porter as a supplement to his economic study of the coals of Canada, and in its initiation he had the advice and assistance of Mr. Edgar Stansfield, Chief Chemist to the Fuel Testing Division of the Mines Branch of the Department of Mines, Ottawa, who has been his chief chemist on the original research. The laboratory

<sup>1</sup> See page 86 ante.

work which was conducted in the Mining Department of McGill University, was done at first by Mr. E. E. Billington, and later by Mr. A. E. Cameron, successively holders of Douglas Research Fellowships in Mining. The following report is largely made up from the notes of these gentlemen.

#### DESCRIPTION OF APPARATUS AND ITS USE.

The research as outlined in advance was as follows:—

1. That each sample of coal be taken at the mine face, and be hermetically sealed at once under mine water in a bottle.
2. That this coal be crushed immediately before use, every precaution being taken to prevent the access of air.
3. That a portion of the wet sample so obtained, be placed in a suitable container through which gases, either dry or moist, at a constant temperature, could be passed.
4. That the container be of such a nature as to prevent radiation of heat to or from the coal and gas during the experiment.
5. That the coal be thus first brought to a constant physical condition by passage of a quantity of a neutral gas through it; i.e., the moisture in the coal should arrive at a state of equilibrium with the moisture—if any—of the entering gas; also any methane or other hydrocarbon physically emitted by the coal at that temperature should be removed, or the velocity of such emission be determined.
6. That the entering gas should first be passed through a suitable gas-washing apparatus to insure its purity.
7. That when the coal and the entering neutral gas reached a condition of equilibrium, the entering gas should be changed to oxygen, which had been previously suitably purified.
8. That any rise in temperature in the coal or its atmosphere of oxygen should be noted by two thermometers placed, the one in the gas inlet of the container, and the other in the gas outlet of the same.
9. That further, any substances emitted by the coal due to chemical action with the oxygen, should be collected by a suitable absorption apparatus.

Diagrams of the apparatus are shown in Figs. 25, 27A, and 29. The original plan called for suction as the means of inducing a current of gas; this meant that when in use the container was under a considerable reduction in pressure, and in practice it proved difficult to prevent leakage of air into the apparatus. It was, therefore, decided to prepare in advance a large quantity of the gas required under pressure, and the apparatus was thereafter so run that the purifying train was under a slight pressure, the absorption under a slight vacuum, and the container as nearly as possible at atmospheric pressure.

*The Gases, Purifying Train, and the Oxidation Apparatus and Accessories.*

**The Gases** were at first produced by chemical methods, and after some experimenting both oxygen and nitrogen of good quality were produced satisfactorily, but it was later found possible to buy both gases of a high degree of purity under high compression (120 Atm). The oxygen contained but 0.2% of impurity chiefly nitrogen, and the nitrogen only about 0.5%

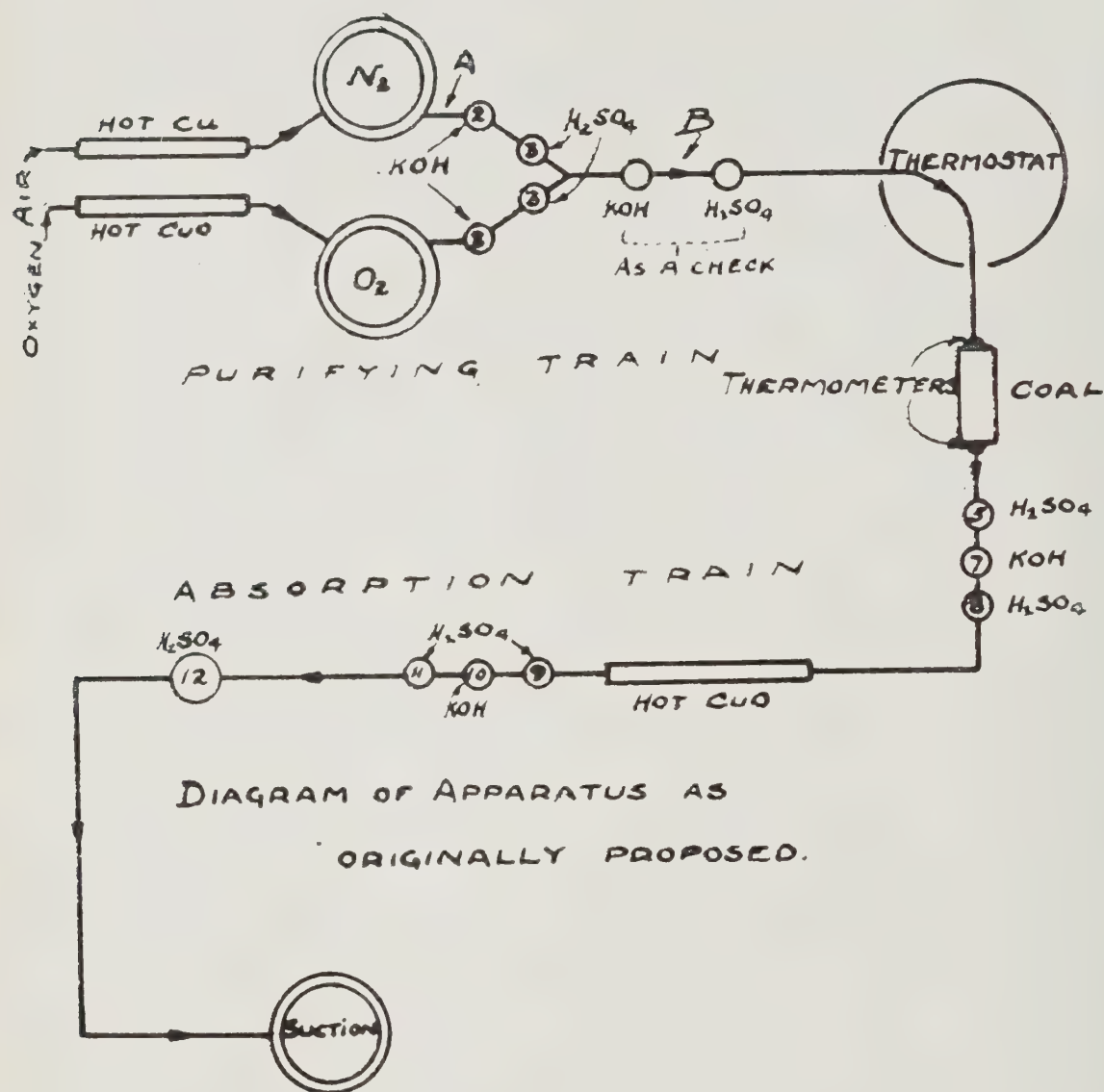


FIG. 25. Diagram of original apparatus. (Porter and Billington.)

of impurity, which could easily be removed as it was chiefly carbonic acid and oxygen. All waste of time in preparing oxygen and nitrogen was thus done away with, and a supply of gas of constant composition assured.

**The Purifying Train** as used underwent but very few alterations throughout the whole series of experiments, the only important change being the substitution of a large U tube containing stick phosphorus (No. 1, Fig. 29), as more satisfactory than the bottle containing pyrogallol solution (A, Fig. 25) in the nitrogen train; this U tube being kept in a dark container to prevent formation of red phosphorus.

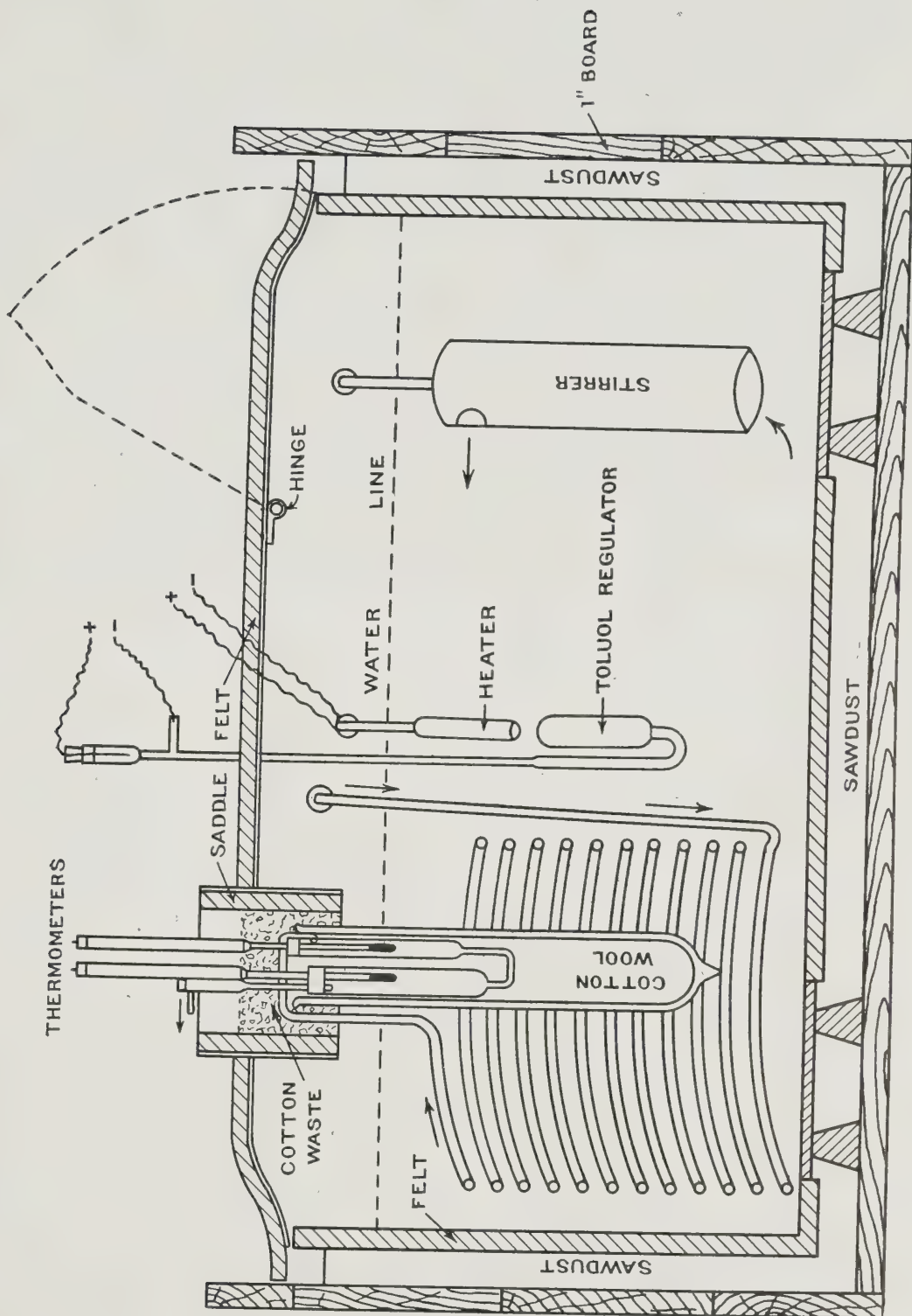
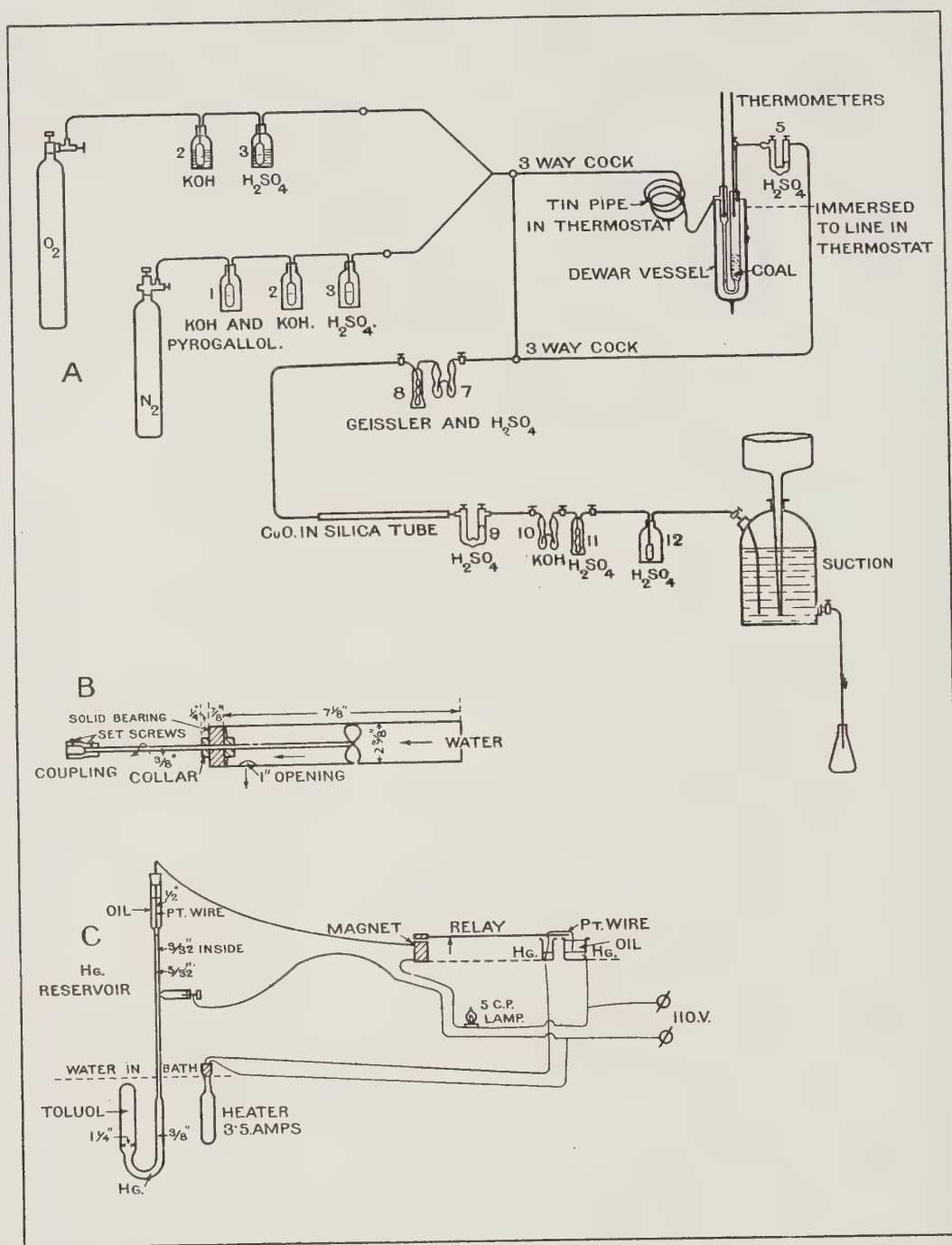


FIG. 26. Original thermostat and contents.

(Porter and Billington.)

The **Thermostat** consisted of a tin-lined copper vessel, 36"  $\times$  13"  $\times$  13"; fitted with a tinned lid. For the arrangement of apparatus in the thermostat, see Fig. 26.



(Porter and Billington.)

FIG. 27. A—General diagram of apparatus.  
 B—Stirrer.  
 C—Thermo regulator diagram.

The thermostat contained water up to a convenient level, and was fitted with a water gauge, so that loss by evaporation might be detected before injury to the heater occurred. The temperature was controlled by means of a toluol mercury regulator, operating a 110 volt, 3.5 amp. water-heater by means of a relay. (Fig. 27C). The water was agitated by means of a motor driven stirrer. (Fig. 27B).

The gas before entering the coal container was led through a 50 ft. spiral of  $\frac{1}{8}$  inch diameter tin pipe coiled in the thermostat bath. The container stood in a deep Dewar vessel, which in the first season's experiments was immersed to within a few inches of its top in the water of the thermostat, to minimize change of temperature of the gas, between the place where the tin pipe left the water and the inlet of the container.

The thermostat was insulated by being completely enclosed in a jacket of thick saddle felt; and stood upon a number of corks in a large box,  $32'' \times 15'' \times 17''$ , having walls  $1''$  thick. The space between the felt and the walls and bottom of the box was filled with dry sawdust. The lid was fitted with a wooden box  $6'' \times 6'' \times 6''$ , having a hole in one end, through which the Dewar vessel which exactly fitted was introduced at will. (Fig. 28B). The other end of the lid was so hinged as to allow of easy access to the stirrer and heating apparatus in case of necessity, without any disturbance of the container and coal.

**The Thermoregulator and Heater** originally made by Mr. Billington, restricted the fluctuation of bath temperature to a range of  $0.2^{\circ}\text{C}$ . After working excellently for two months the glass of this regulator crystallized and broke in the middle of an experiment; its place was taken by another one of similar design (Figs. 26 & 27C), but made with glass tubing of  $\frac{3}{16}''$  outside diameter, and  $\frac{1}{8}''$  bore, whereas the original tubing had been of  $\frac{11}{32}''$  diameter, and  $\frac{1}{16}''$  bore. The later experiments were all conducted using this regulator, which permitted fluctuation of bath temperature over a range of  $0.6^{\circ}\text{C}$ .

It may be worthy of note that the regulators always did better work when the stirrer was in operation, as a certain amount of vibration made the mercury contact more prompt.

The spark at make and break between the platinum wire and mercury surface was extinguished by means of heavy transformer oil. This oil required cleaning out every six hours, as the sparking caused sediment to form which interfered with efficient regulation.

**The Stirrer** (Figs. 26 & 27B) was made entirely of brass, and was operated by a  $\frac{1}{6}$  H.P. Crocker and Wheeler motor, belted to a countershaft, from which the stirrer was driven by means of a variable speed friction drive.

**The Container** was changed several times before a satisfactory form was devised. The first suggestion was the use of a vacuum vessel fitted with an inlet at the bottom, in which the coal might be placed without the use of any inner vessel. (Fig. 28A). This very simple arrangement was abandoned because it necessitated the use of a submerged connexion between the vessel and the end of the tin pipe; it also was found to be too cumbersome to allow of accurate weighing of the coal and vessel when desired.

The form of container finally adopted was that shown in Figs. 26 and 28B. Into this apparatus the coal was at first placed in a tight-fitting gauze

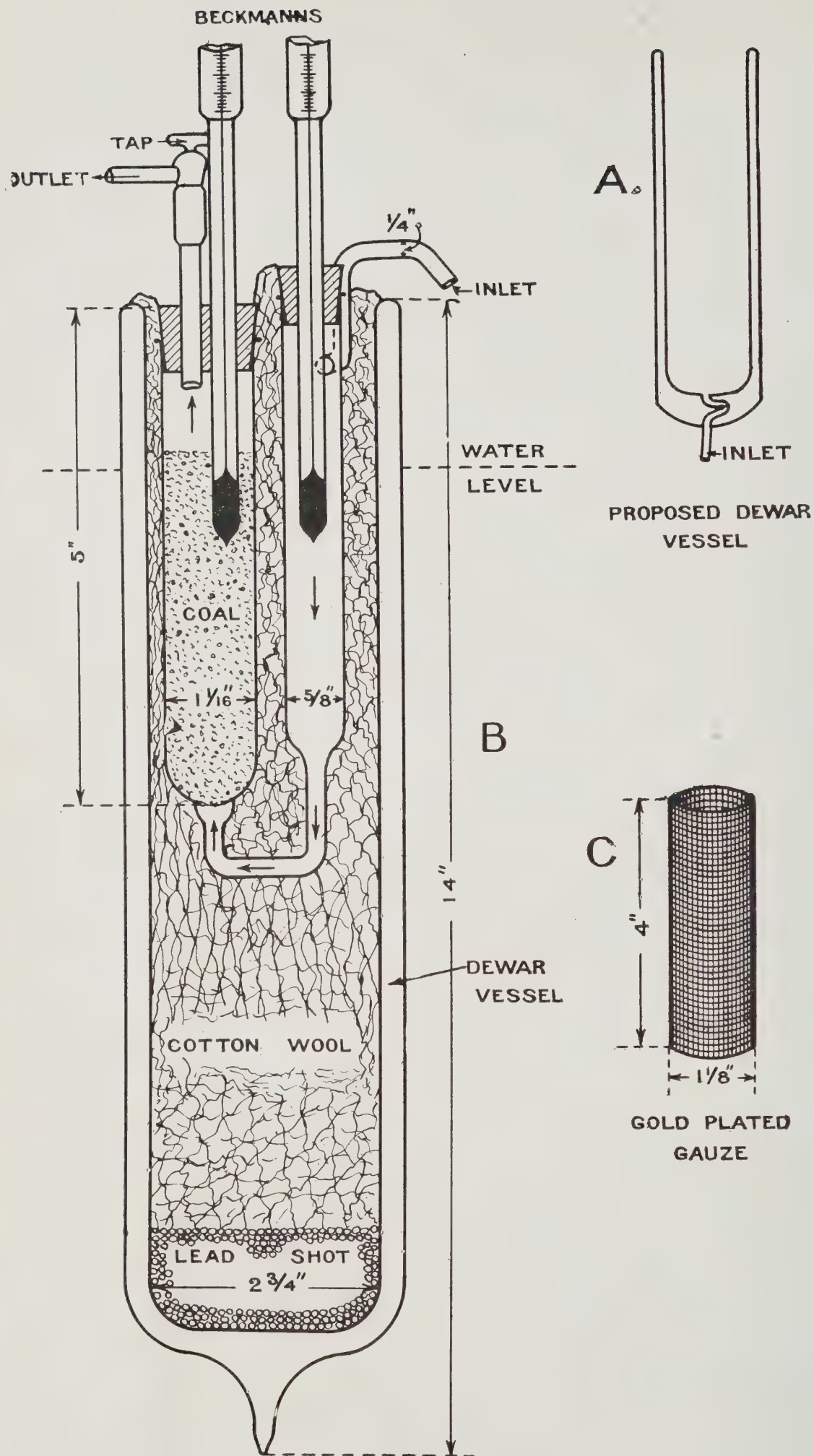


FIG. 28. Details of apparatus.

receptacle, 4" long by about  $1\frac{1}{8}$ " diameter made of 60-mesh gauze which had been previously gold plated (Fig. 28C). The idea in using the gauze was that both gauze and coal might be readily removed for weighing, and quickly replaced, no gas connexions having been disturbed. This method was given a good trial, but proved troublesome, as in spite of the fact that the gauze was a very tight fit in the glass container, too much gas passed between the gauze and the wall of the vessel, instead of through the coal. When, during this trial, it was required to determine the weight of the gauze and coal, they were quickly put into a special weighing tube in which the air could be replaced at will by nitrogen.

In the later experiments the gold gauze was not used, the coal being simply introduced into the container on a bed of glass wool, (Fig. 28B), and container, coal and special stoppers were weighed together when required.

The Dewar vessel was fitted into the box Fig. 26, by means of a piece of rubber cloth wedged in with cotton waste, to prevent the admission of too much moist air into the container box. The container itself was packed into the Dewar vessel with fine cotton wool. See Fig. 28B.

The Beckmann thermometers, Figs. 26 and 28, were lent by Dr. H. T. Barnes, F.R.S., Director of the Department of Physics at McGill University; they were tapped before reading by an electric buzzer. Readings were taken by means of a telescope from a distance of four feet.

### *The Absorption Train.*

By reference to Figs. 25, 29, and 34 it can be readily seen that this train underwent considerable changes during the preliminary experiments. Fig. 25 represents the train as originally designed, Fig. 29 the form used for the first series of experiments, and Fig. 34 its 1914 form. The changes were mainly substitutions of dry or solid absorbents for the wet ones in order to lessen the weight of the train and reduce the head to be overcome by suction.

The reactions which might take place between coal and gas during any experiment were assumed to be as follows:—

When the coal is submitted to the action of dry nitrogen, purely physical changes occur:—

- (1) Mechanical drying or evaporation of moisture;
- (2) Evolution of carbon dioxide, if, as is commonly the case, this gas was contained in the original coal under pressure;
- (3) Evolution of methane or other hydrocarbons ( $C_nH_{2n+2}$ ) from the coal, these gases almost always existing in the coal as it occurs in the seam.

When oxygen is being passed over the coal, oxidation of some of its constituents usually takes place, the substances formed by this chemical

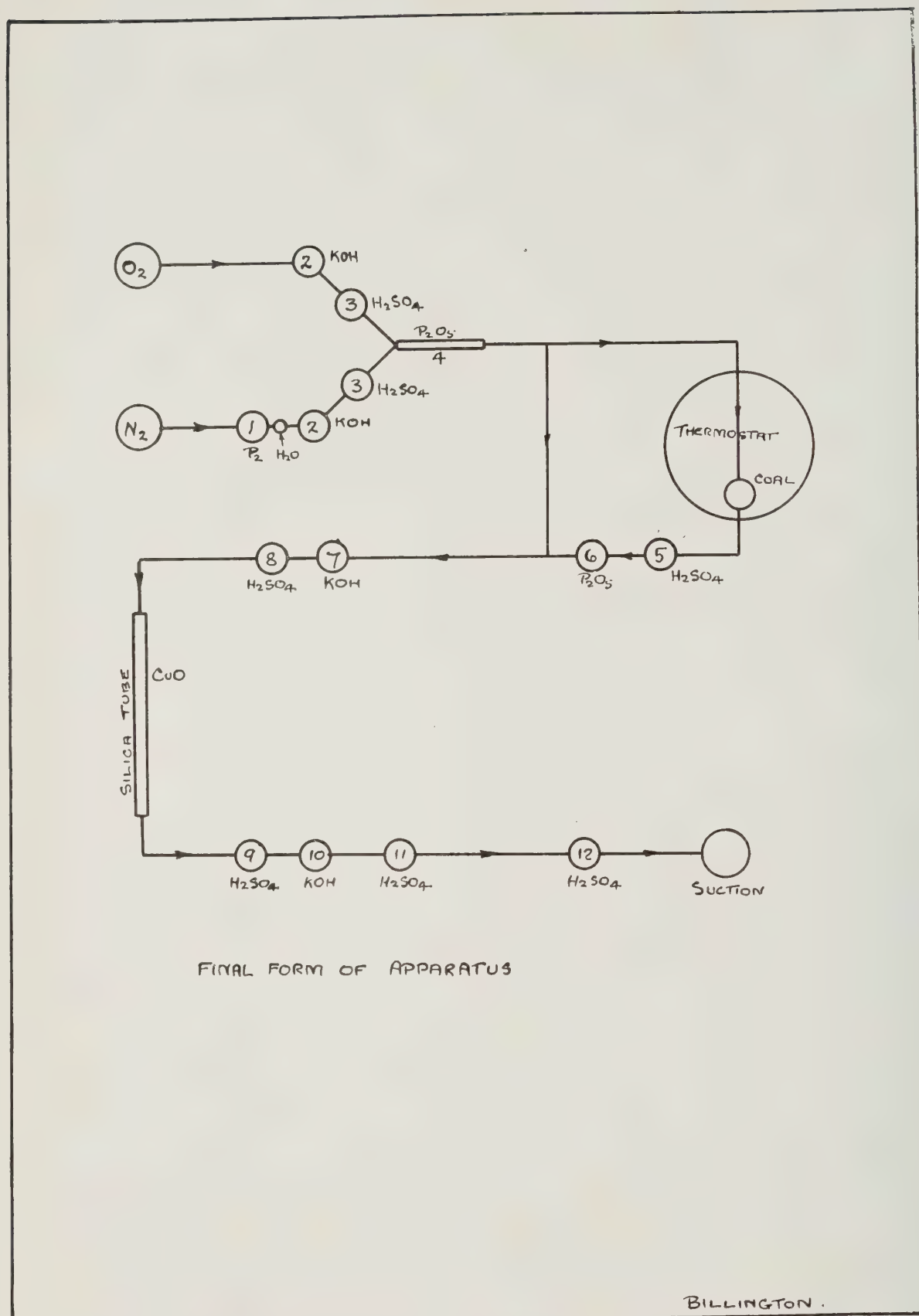


FIG. 29. Second form of apparatus.

(Porter and Billington.)

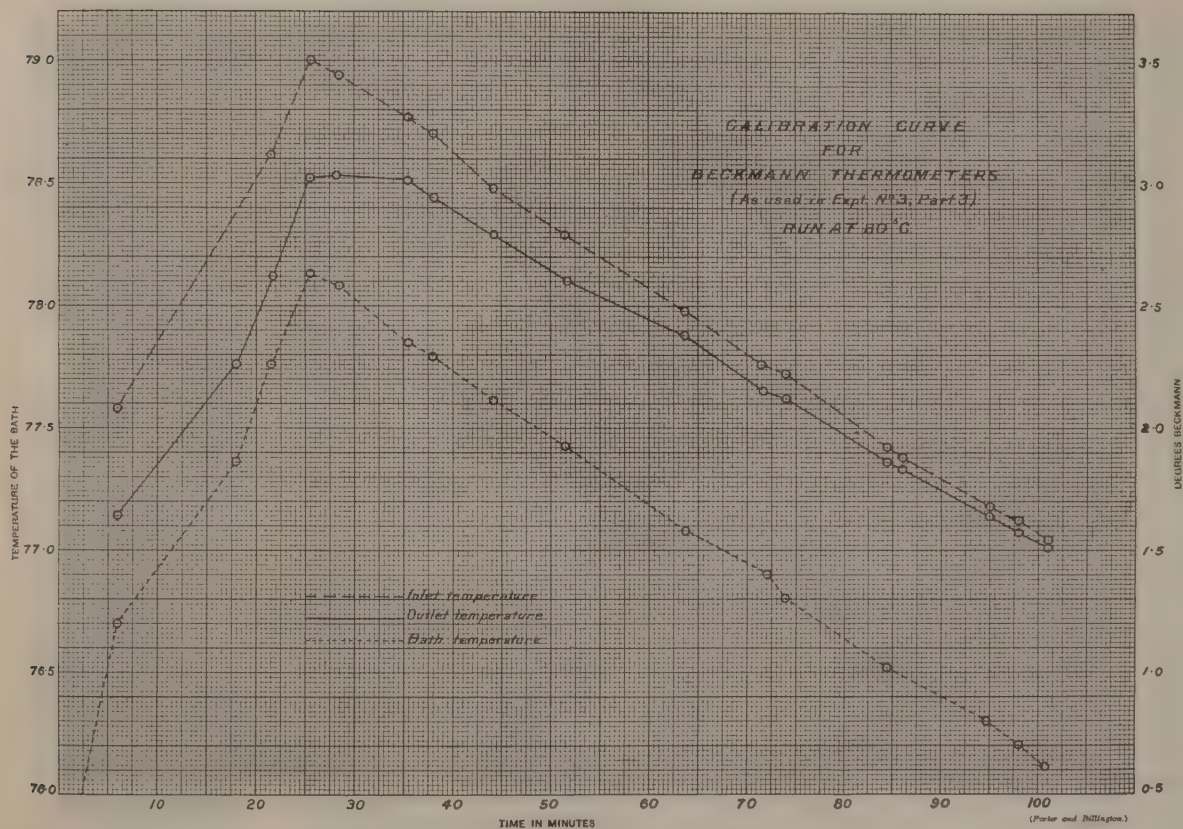
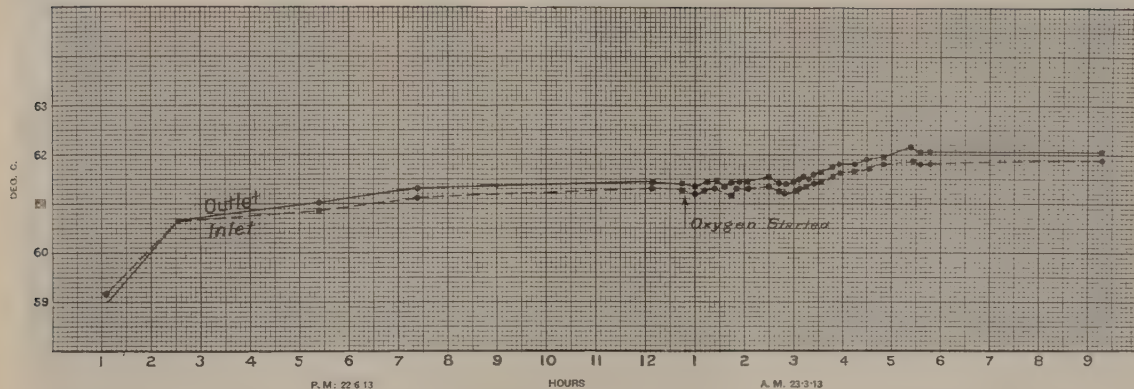


FIG. 30. Calibration curve of Beckmann thermometers.



EXPT. III, PART I



EXPT. III, PART 2

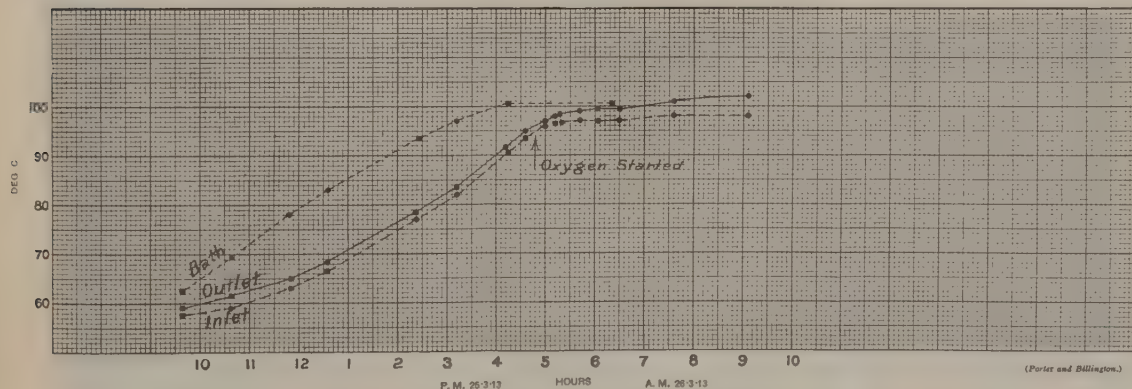
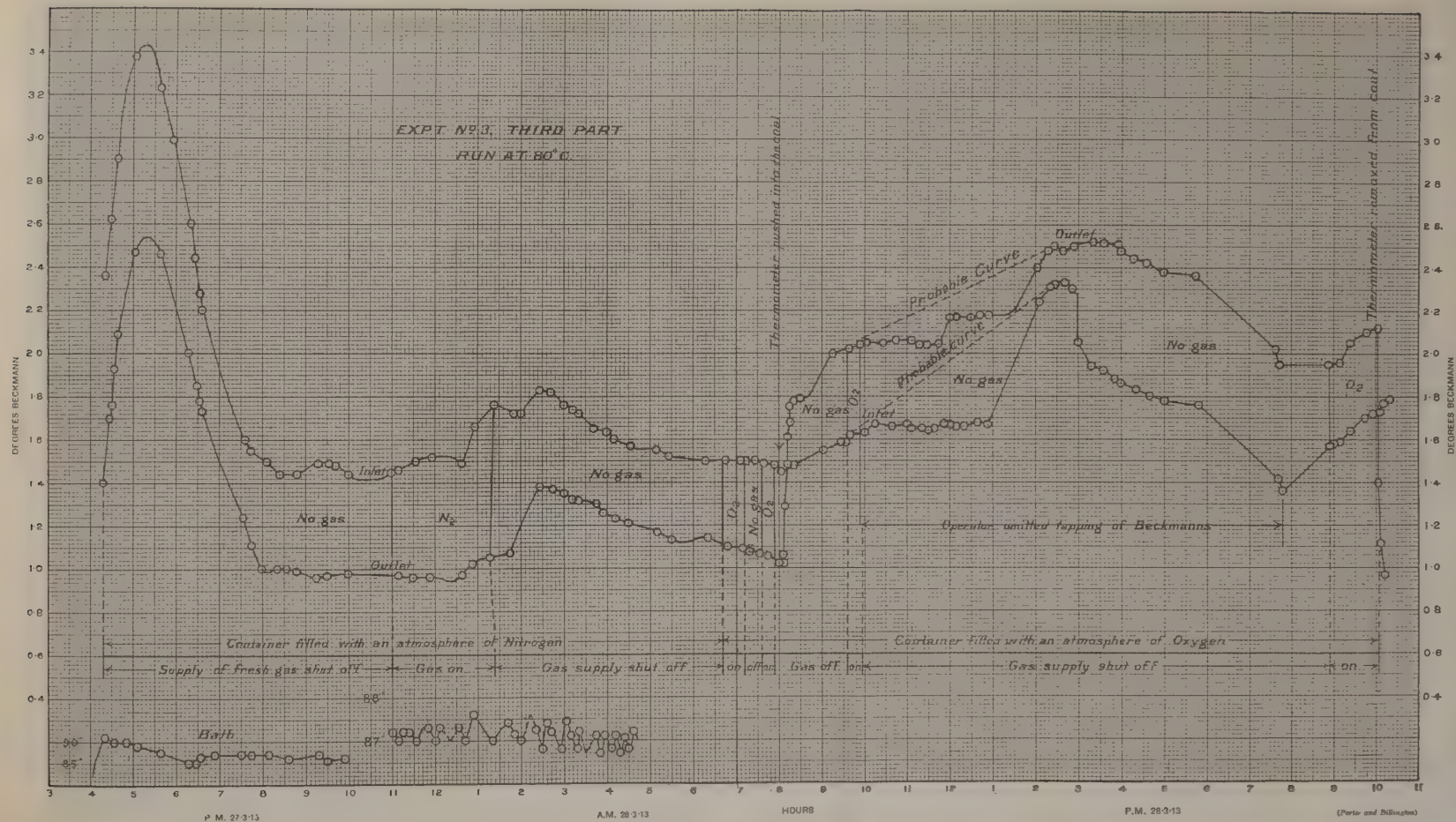


FIG. 31. Graphic record of experiment III, Parts 1 and 2.

(Porter and Billington.)





A.M. 28-3-13

HOURS

P.M. 28-3-13

(Paris and Billington)

FIG. 32. Graphic record of experiment III, Part 3.







action would probably consist of water, carbonic acid and hydrocarbons split off from the coaly matter.

Any water evolved, either physically or through chemical action, was absorbed in sulphuric acid and phosphorus pentoxide, (tubes Nos. 5 and 6 in Fig. 29).

Carbon dioxide was absorbed by the Geissler bulb containing potassium hydroxide, (tube No. 7 in the diagrams) any moisture lost by No. 7 was collected in the guard tube of sulphuric acid (No. 8).

The silicon combustion tube containing red-hot copper oxide was assumed to burn up all hydrocarbons to carbon dioxide and water, which products were collected by means of potash bulbs and a sulphuric acid tube similar to those described above.

Before weighing each piece of apparatus it was wiped with a clean linen cloth, and allowed to stand ten minutes in the balance case. The weights were counted as they lay on the pan, and checked by observing the blank spaces in the weight-box.

With the apparatus as described above, Mr. Billington carried out a first series of experiments the results of which are clearly shown in the appended curves and table. The coal used was a semi-lignite from Kipp, Alberta. The sample was taken at the face of the workings by Mr. de Hart, and immediately packed in mine water and sealed as were all other samples dealt with in both series of experiments. In all, four experiments were run. Of these the first two were of a preliminary nature, made to test the apparatus and gain experience, and are not reported, as no results were obtained which justified publishing.

The curves Figs. 31 and 32 show the results of the third experiment which was run in three parts. In this experiment no attempt was made to calculate the ratio of evolved substance to the oxygen absorbed, but attention was paid solely to the temperature rise with oxygen.

In the fourth experiment a complete test was made over some 72 hours. The results of the absorption train calculations are shown in Table XLIII, p.124. The original Time-Temperature record drawn by Mr. Billington, was some twelve feet long and this has been considerably reduced and reproduced in Fig. 33.

The third curve in Fig. 33 has been obtained by plotting the difference between the ordinates of the outlet and inlet thermometer curves in order to more clearly show the temperature rise in oxygen, so that it may be directly comparable with the results obtained by Mr. Cameron in the later experiments.

As shown by the last curve, the maximum temperature rise obtained with oxygen was of the order of  $0.7^{\circ}\text{C}$ . There was, however, an average difference of  $0.2^{\circ}\text{C}$ . between the inlet and outlet thermometers at all times,

so that in reality the temperature rise was of the order of  $0.5^{\circ}\text{C}$ . with oxygen and not  $0.7^{\circ}\text{C}$ . as shown. The curve has not been corrected for the average difference in temperature throughout the experiment.

The results obtained by Mr. Billington in the above tests should be considered preliminary to a second series of tests made by Mr. Cameron in the winter and spring of 1913-14. The results of both series will be considered in drawing final conclusions.

TABLE XLIII.

**Record of Results—Experiment IV.***(Porter and Billington)*

Coal taken: 20.6335 grammes. Temperature of bath:  $60^{\circ}\text{C}$ .

Time in minutes.	Water evolved.	Carbon dioxide evolved.	Hydrogen in hydrocarbons evolved.	Carbon in hydrocarbons evolved.
0.....	Atmosphere in	apparatus is nit	rogen	
946.....	.0185	.0133	.0112	.0416 ?
1,750.....	.0075	— .0023	.0000	— .0029
1,860.....	Atmosphere in	apparatus changed	to oxygen	
2,118.....	.0155	.0056	.0035	.0006
2,880.....	.0060	.0102	— .0021	.0073
3,634.....	.0000	.0050	.0020	.0047
4,571.....	.0205	.0223	.0191	.0176

NOTE,—Apparent gain in weight of coal =  $0.4858$  gramme.

Apparent gain in weight of coal per gramme of coal =  $0.0236$

Real gain in weight of coal, including weight of C and H evolved =  $0.7071$  gramme.

$\text{CO}_2$  evolved weighed  $0.0541$  and therefore accounts for less than  $\frac{1}{10}$  the  $\text{O}_2$  absorbed.

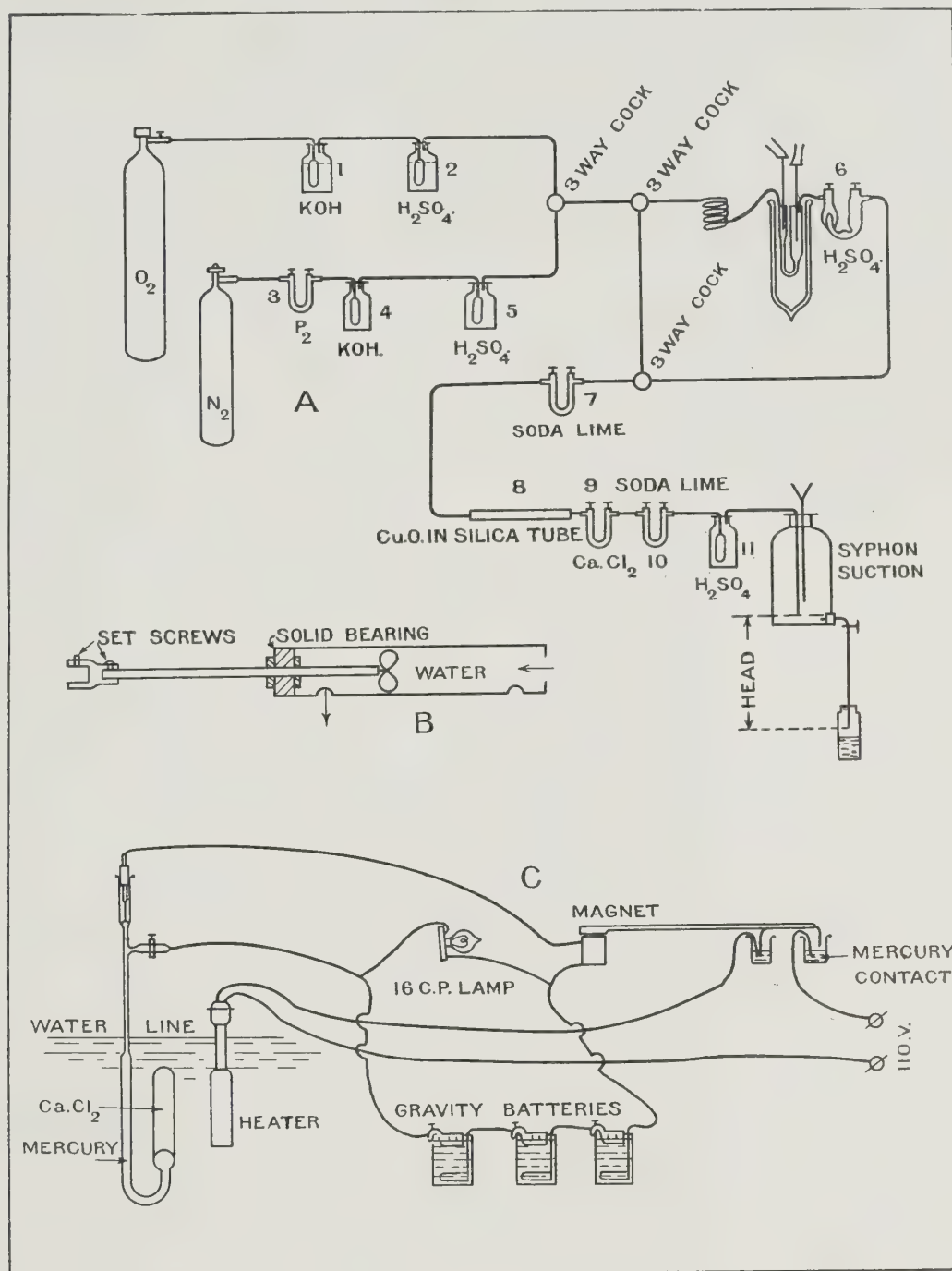
The analyses of coal before and after the experiment showed no detectable difference.

Before beginning the second tests several changes were made in the apparatus to meet difficulties which developed in the earlier work.

*Changes in the Apparatus.*

Fig. 34 shows the general layout of the apparatus as reconstructed. A comparison with Fig. 29 will show that the purifying train underwent no alteration with the exception of the removal of the long phosphorus pentoxide tube (4). This was done to economize space and simplify the apparatus, it having been found by analysing the gases that this phosphorus pentoxide tube was an altogether unnecessary guard, there being no trace of moisture in the gas after it left the last sulphuric acid bottle on its way to the thermostat.

Considerable change, however, was made in the thermostat, the principal one, as shown by comparison of Fig 26 with Fig.35, being the removal of the Dewar vessel from its position in the bath to a separate box attached to the end of the thermostat. This was done on Billington's suggestion



(Porter and Cameron.)

FIG. 34 A—General diagram of final apparatus.  
B—Stirrer.  
C—Thermo regulator diagram.

in order to make the gas connexions more accessible and to minimize any chance of moisture from the bath water finding its way into the Dewar vessel and thus possibly giving a variable temperature in that vessel.

When first put into the box the Dewar vessel was wrapped with 1 inch of felt and the whole packed around with sawdust, but it was soon found

that there was a sufficient difference in temperature between the inside and outside of the Dewar vessel to cause appreciable loss in temperature in the vessel, and consequently the box was further modified as shown in Fig. 35.

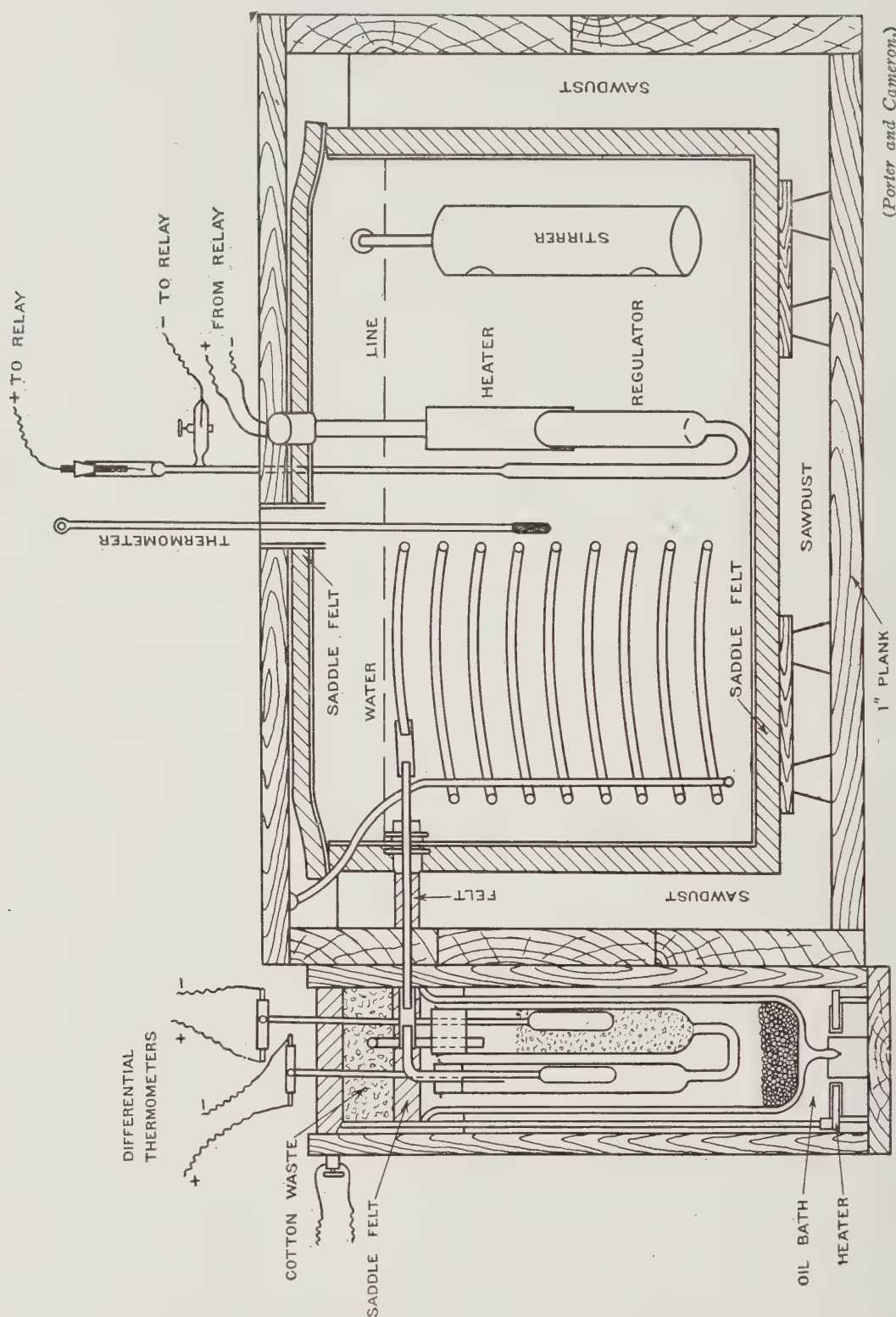
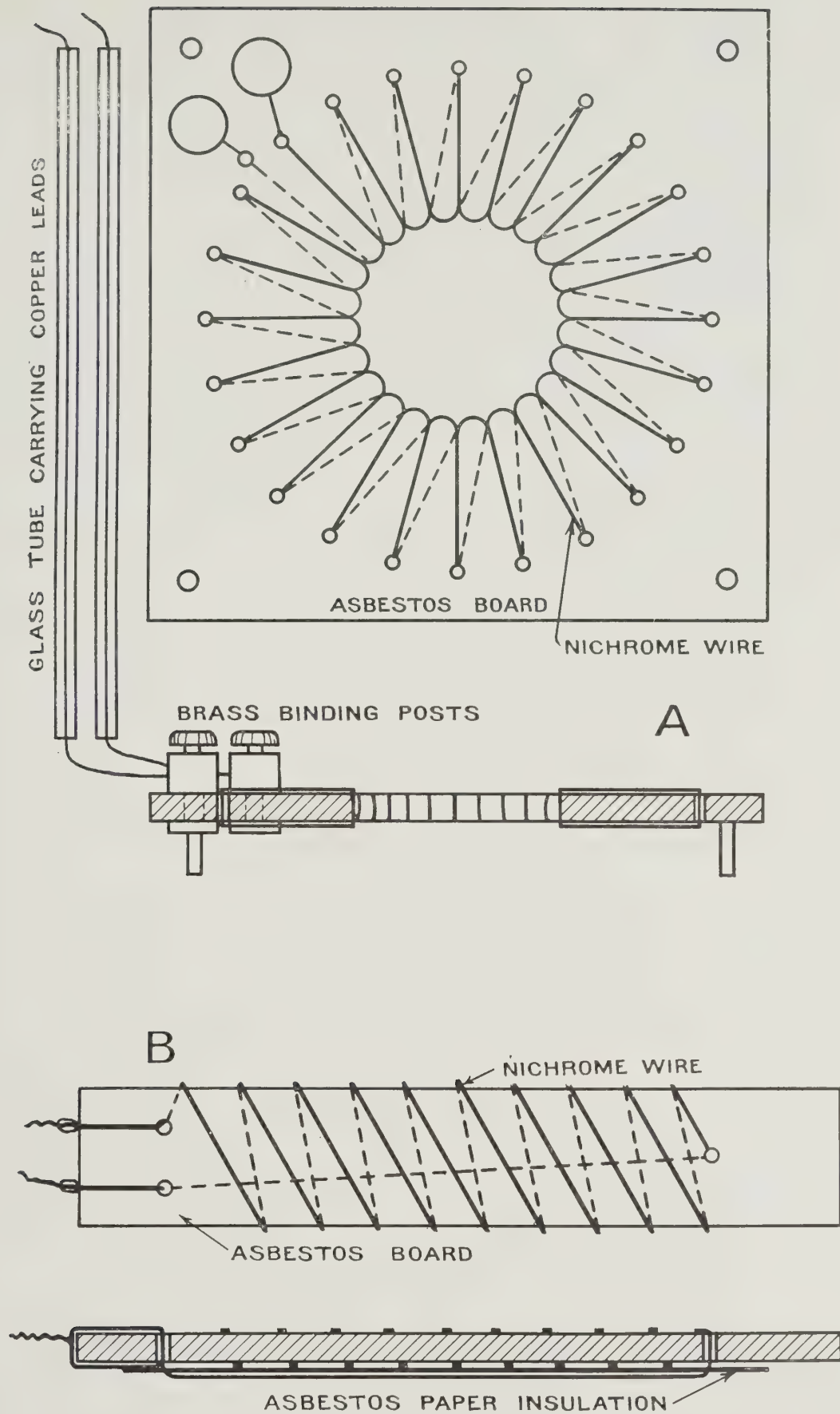


FIG. 35. Diagram of final thermostat and contents.

The box  $6'' \times 6'' \times 18''$  was made water-tight by lining with heavy galvanized sheet iron, and, after the Dewar vessel had been placed in position, was filled with a heavy transformer oil. In the bottom of the box, but insulated from contact with the lining, was placed a small electric heater



(Porter and Cameron.)

FIG. 36. Electric heaters for oil bath and container.

which, when connected to the electric current through a variable resistance in the form of a bank of lamps, was able to keep the oil bath at any desired temperature. This heater is shown in Fig. 36A and consists of a piece of asbestos shingle  $4" \times 4" \times \frac{1}{8}"$  upon which is wound 6 feet of "Nichrome" high resistance ribbon wire. The shingle is cut square on the outside and a  $1\frac{1}{2}"$  diameter circle cut out of the centre and nicked to receive the wire. A ring of small holes was punched  $1\frac{3}{4}"$  from the centre all around and as close as possible together and the wire threaded as shown in the diagram. In this way the wire is insulated on the outside edge from contact with the iron lining of the box. The whole is supported from the bottom by four short wooden pegs. Thin glass tubes carry the bare copper wire leads from the heater to the top of the box where they are connected to the bank of lamps by permanent screw terminals. When in position the heater is so placed in the box that a cork placed on the bottom of the Dewar vessel just fits into the circle cut out of the centre of the heater.

A current of 5.0 amperes was used to heat the oil up to the required temperature (about  $80^{\circ}\text{C}.$ ) and thereafter 2.0 amperes were continually applied to make up for radiation losses through the box. The heater being placed at the bottom of the box convection currents generated in the oil are sufficient to heat the oil uniformly throughout, no mechanical stirring being necessary.

In order to save the large amount of time that would be necessary for the gas alone to heat the container to the desired temperature, a second small heater, as shown in Fig. 36B, is used to heat up the inside of the Dewar vessel. It consists of a flat piece of asbestos board  $1" \times 3" \times \frac{1}{8}"$  around which is wound about 2 feet of "Nichrome" wire, the whole being insulated by a covering of thin asbestos paper wrapper. The leads, connecting the heater to a pair of terminals situated on the outside of the box, are made of ordinary flexible insulated lamp cord with solder connexions to the "Nichrome" wire.

This heater was also run through a bank of lamps, and it was found after some experiment, that the same bank would do for both. The oil bath was first heated up to a little above the desired temperature and the connexions then transferred to the second heater. This one heated up much quicker and the resistance of the bank of lamps was then arranged to keep it at a constant temperature only breaking the connexion occasionally to heat up the oil bath as it cooled below a certain point. Thus by altering the connexions occasionally it was a comparatively easy matter to keep both temperatures fairly constant. At the end of about an hour it was found that the thermometer in the Dewar vessel would no longer fall upon breaking the connexions, but would remain constant because by then the walls of the Dewar vessel, the container, and the coal had all reached the same temperature, and there being but very little radiation this loss was counteracted by the heating effect of the incoming gas. When this condition was obtained the connexions were made permanently to the heater in the oil bath.

A further modification of the Thermostat consisted in the substitution of a battery of 3 gravity cells supplying the current necessary to operate the relay in the heater circuit of the bath (Figs. 27C and 34C) in place of taking current from the 110 volt mains. By this means sparking was completely done away with in the glass regulator thus minimizing the possibility of delay due to the regulator burning out.

### *The Absorption Train.*

The train suffered a few minor changes from Billington's design, as can be seen by Figs. 27A, 29, and 34A.

In the first Cameron experiment dry absorbents alone were used;  $\text{CaCl}_2$  for moisture and soda lime for  $\text{CO}_2$ , but it was found that the U tube containing  $\text{CaCl}_2$  clogged early in the experiment stopping the flow of gas, so a vessel of  $\text{H}_2\text{SO}_4$  (6, Fig. 34 A) was substituted in the later experiments. It was also felt that  $\text{H}_2\text{SO}_4$  made a better dryer for the comparatively large amount of water coming over from the coal as the bubbles rising through the liquid gave better and surer contact between the gas and the absorbent. For the very small quantities of water produced from the burning of the hydrocarbons the dry absorbent was found very satisfactory and was used throughout the tests.

As mentioned above the dry absorbents used were  $\text{CaCl}_2$  for moisture and soda lime for  $\text{CO}_2$ . Calcium chloride was substituted for  $\text{P}_2\text{O}_5$  as used by Billington solely because a good supply was found ready at hand in the laboratory. Soda lime (7 and 10, Fig. 34 A) was considered a better absorbent for the gas than a solution of  $\text{KOH}$ , and moreover its use eliminated the necessity of weighing an extra moisture absorbent after each  $\text{CO}_2$  absorbent. The upper half of the second arm of the U tubes containing soda lime was filled with  $\text{CaCl}_2$  to take care of the moisture developed by the reaction of  $\text{CO}_2$  upon the soda lime.

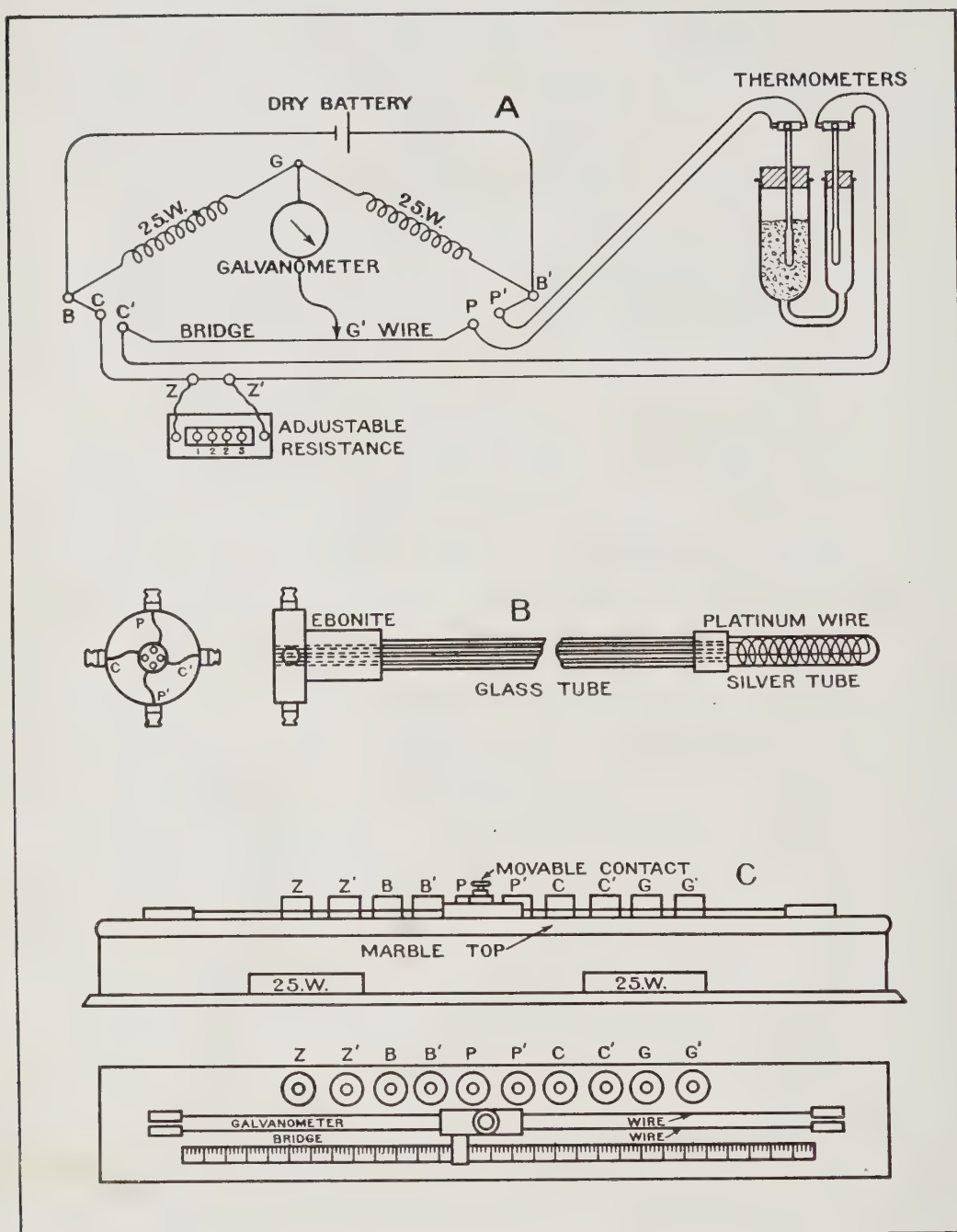
### *Temperature Readings.*

In order to obtain very accurate readings of the temperature differences between the incoming gas and the coal, two differential electric resistance thermometers specially designed by Dr. H. T. Barnes, and made by Mr. N. T. Pye in the Macdonald Physics Building of the University, were used in place of the Beckmann thermometers used by Billington. Differences of temperature of one five-hundredth of a degree were easily observable with these instruments.

This apparatus consisted essentially of three parts, as shown diagrammatically and in detail in Fig. 37.

1. The two differential thermometers.
2. A specially constructed Wheatstone's Bridge.
3. A Broca galvanometer.

The thermometer as shown in Fig. 37B consists of a thin silver tube, 2" long, encasing a coil of very fine platinum wire of 38.50 ohms resistance wound about a mica centre. The thermometer is connected to a glass tube 8" long and  $\frac{3}{16}$ " diameter. The leads, consisting of fine silk in-



A — DIAGRAM OF THERMOMETER CONNECTIONS (*Porter and Cameron.*)  
 B — DETAILS OF THERMOMETER  
 C — DETAILS OF WHEATSTONE'S BRIDGE

FIG. 37. Details of electric thermometers.

ulated copper wire are further insulated from contact with each other in the glass tube by being carried in  $\frac{1}{32}$ " glass tubing to the terminals at the top of the thermometer. Each thermometer also has in it a pair of compensator leads connected to separate terminals at the top so that the two

instruments may be used either together as differential thermometers or separately for measuring actual temperatures. In the experiments they were always used differentially and, therefore, the compensators were not needed. A diagram of the thermometer connexions is shown in Fig. 37A.

The Wheatstone's Bridge is shown in detail in Fig. 37C. It consists of a wooden box 3"×3"×24" having a solid marble top. The two equal arms of the bridge of 25 ohms resistance each are placed inside the box and all connexions are led to terminals on the marble top. The wire itself is of such size that a temperature difference of 1°C between the thermometers is equivalent to a movement of the sliding galvanometer connexion of 60 mm. and the wire being 600 millimetres long a possible temperature difference of 5°C on either side of the zero reading is shown directly upon the scale. A further resistance box made of the same wire as the Bridge wire may be inserted in series with one of the thermometers, and is so arranged as to give readings of anything from one to ten degrees, so that with the apparatus it is possible to read with great accuracy any temperature difference between the two thermometers up to 15°C.

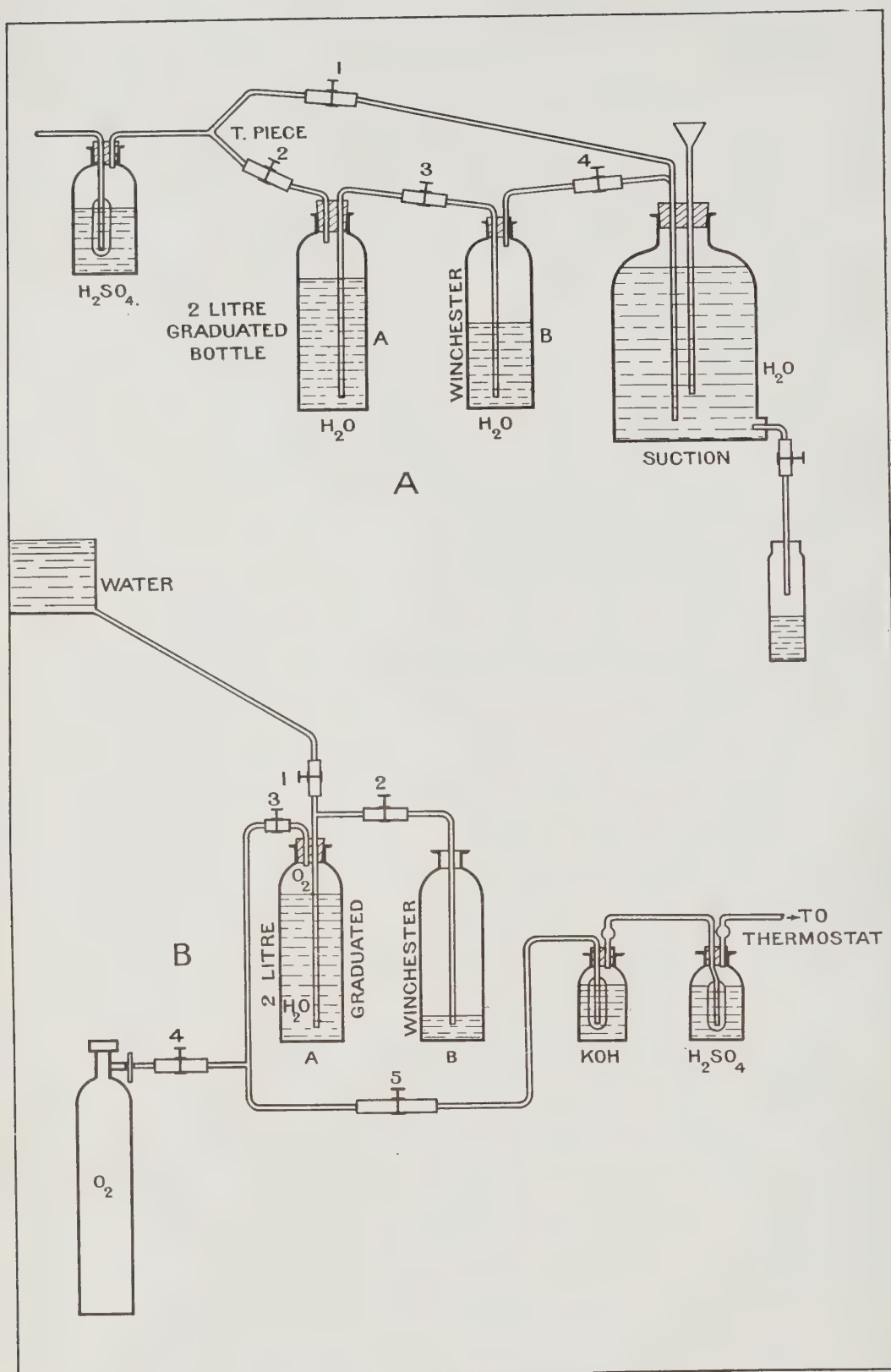
The galvanometer used was of the standard Broca type, obtained, equipped complete with Nernst lamp and scale, from the Cambridge Scientific Instrument Company.

As mentioned above, the Bridge was designed to have a movement of 60 mm. for every degree of temperature difference, but before starting the experiments, calibration tests were made by taking a series of readings with the thermometers in baths of different temperature, using standard mercury thermometers, reading to one-tenth of a degree. All readings were made simultaneously and upon calculation it was found that the average movement was 60.15 mm. per degree, which is well within the limit of accuracy of reading the mercury thermometers.

#### *The Coals used.*

In order that close comparison might be made with Lamplough and Hill's work it was decided that at least one of the coals used should be as nearly as possible the same as some that they experimented on, and therefore samples were obtained, through the kindness of Mr. George Blake Walker and Sir William Garforth, from various collieries in England working the Barnsley seam. These coals were used for five experiments Nos. V to IX. It was also thought advisable to experiment with some Canadian coal especially liable to spontaneous combustion, and for this purpose the sample used in experiments X and XI was obtained through the kindness of Mr. Cadwallader Evans, from the Acadia Coal Company workings on the Cage Pit seam at Stellarton, Nova Scotia.

Directly after reaching the laboratory the samples, which were sent from the mines in sealed vessels filled with mine water, were crushed under mine water to about 10—30-mesh and hermetically sealed in glass bottles, stored under water.



(Porter and Cameron.)

FIG. 38 A—Apparatus for measuring rate of flow of gas.  
B—Apparatus for supplying oxygen.

### The Experiments.

Before starting the experiments it was decided that some means should be had of determining the approximate rate of flow of the gas through the apparatus, and for this purpose Dr. Porter designed the apparatus shown in Fig. 38A.

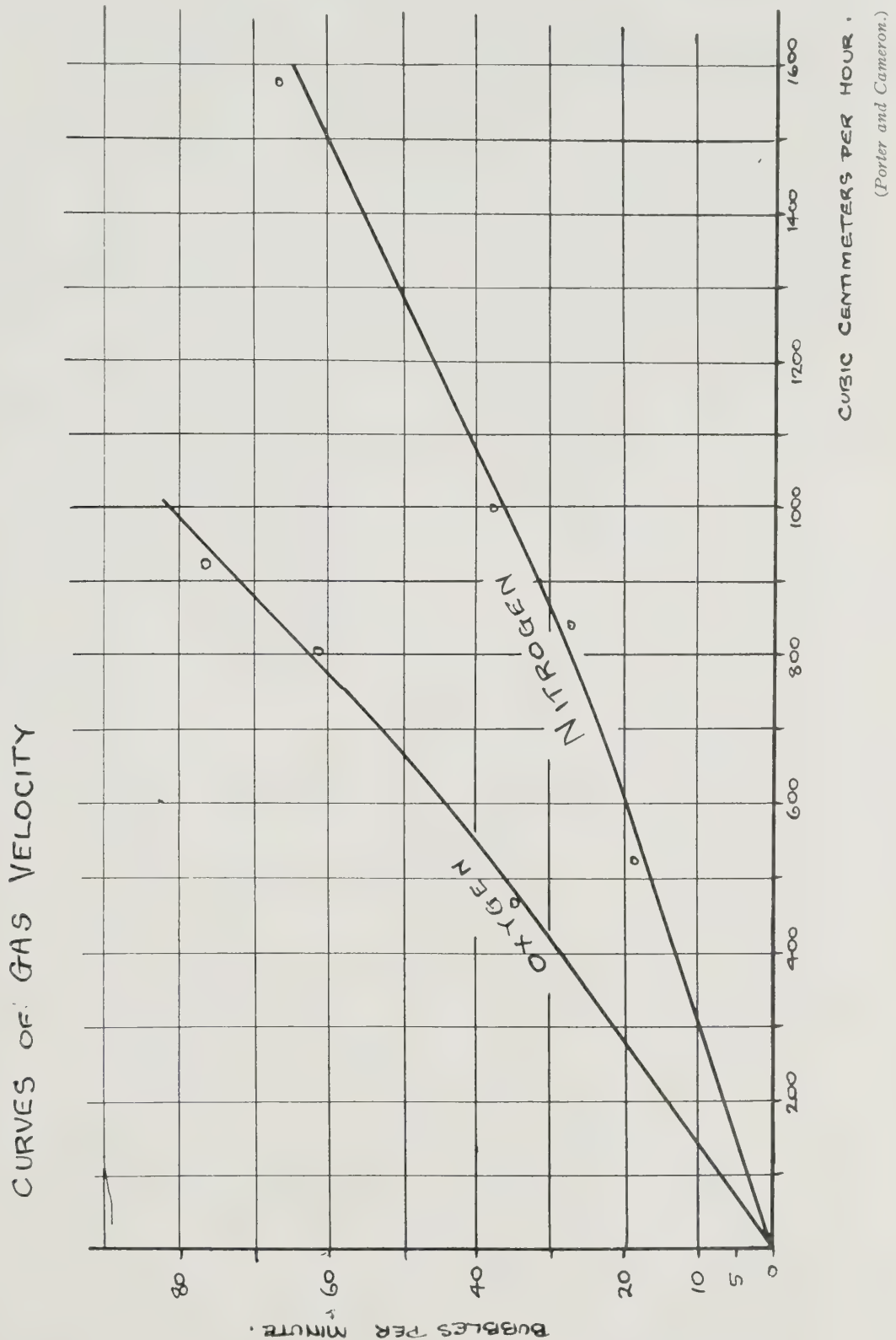


FIG. 39. Curves showing gas velocity.

(Porter and Cameron.)

It was inserted at the end of the absorption train between the last  $\text{H}_2\text{SO}_4$  bottle and the suction (Fig. 34A), and consisted of a graduated bottle (A) connected by means of a syphon to an ordinary Winchester (B), which

in turn was connected by a T-piece to the suction. A by-pass (I) was inserted so that the gas could flow direct from the train to the suction when measurements of the rate of flow were not being taken. A was filled with water to the cork and B was placed at a slightly lower level than A in order to help the suction overcome the extra head of water. With cock 1 closed and cocks 2, 3, and 4 open, the suction causes a suction in B, which causes the water from A to flow over into B making a slight vacuum in A which in turn draws gas from the train. The flow will of course be no faster than the gas is fed to the purifying trains from the storage tanks, and, therefore, different rates of flow of gas can be correlated with the number of bubbles passing some bottle in the purifying train, and the rate thereafter determined by counting these bubbles from time to time. In this way the curves, Fig. 39, were obtained. The oxygen curve shows the rate of flow of oxygen through the  $\text{H}_2\text{SO}_4$  bottle 2, Fig 34A, in bubbles per minute, and the nitrogen curve, the rate of flow of nitrogen in bubbles per minute through the  $\text{H}_2\text{SO}_4$  bottle No. 5, Fig. 34A.

This is of course by no means an accurate determination, but it proved sufficiently reliable for the purpose and with a little care about the adjustments the experiments could all be made under approximately identical conditions.

In order to obtain reliable results the coal had first to be thoroughly dried, and before all experiments this was done in the following manner.

The coal on being taken from the storage bottle was first placed in a filter for a few moments to allow surface water to drain off. From here it was transferred to a large sheet of coarse filter paper for a brief time and as much more moisture as possible extracted. Then it was placed in an atmosphere of nitrogen in a small flask and tightly corked with a rubber stopper through which projected a capillary glass tube. The flask was then placed in an oven and kept at a temperature of  $105\text{--}110^\circ\text{C}$ . for from three to five hours until upon cooling and weighing the coal was found to remain constant as to weight. In this way all moisture was removed with very little contact with air and consequent absorption of oxygen.

The primary object of the experiments being a study of the heat evolution due to the action of oxygen, they were run only long enough to produce a decided rise in the temperature of the coal, and usually a period of some 15 hours sufficed. No attempt was made to determine the rate of absorption of oxygen as this would have necessitated long extended experiments such as No. IV of Billington's work. Moreover, owing to the short period of time over which each experiment extended it was thought unnecessary to make a detailed study of the rate of evolution of the various gases coming from the coal, as Billington did in experiment IV, and only the total amount of evolved substances was obtained at the end of each experiment.

Two series of experiments were made, one showing the effect of dry gas upon the coal and the other the effect of a saturated gas. In both cases, of course, the coal was previously thoroughly dried in order that

the true weight of coal should be known. It had been hoped to experiment with several different coals, but unfortunately owing to delays, the length of time necessary to construct and test the apparatus and other unforeseen difficulties, reliable results were obtained from three coals only.

Seven experiments in all were made, four using dry gas and three using saturated gas. The bath temperature for all experiments was 80°C, as it was felt that at this somewhat elevated temperature more rapid oxidation would probably take place and definite results would be more quickly forthcoming.

In the experiments with saturated gas a slight change in the apparatus was necessary. For saturating the gas at the temperature of the bath a small gas wash bottle containing distilled water was inserted in the thermostat between the coil of piping used to heat the gas and the pipe leading to the coal container. This was so connected that the gas bubbled through the water. It was also necessary to insert a condenser between the container and the first sulphuric acid bottle in the absorption train to collect the excess moisture coming over. The condenser consisted simply of an air tight bottle set in an ice bath.

The gas being dry until it reached the wash bottle it was expected that, as the change in weight of the bottle, and the weight of water coming over into the condenser were known it would be a simple matter to calculate the amount of water absorbed by the coal; but unfortunately it was found that in all cases some water worked back into the coil of tin piping in the thermostat probably by diffusion. Moisture determinations therefore had to be made on the coal after the experiments.

### *Calculations.*

The weights of the water, carbonic acid and hydrocarbons given off during the experiment are obtained by very simple calculations from the weights of the respective elements of the absorption train before and after the test. The weight of oxygen absorbed is obtained by adding the sum of the three above items to the algebraic<sup>1</sup> increase in weight of the coal as determined by weighing the container before and after the test. The volume of oxygen absorbed is then calculated from the following formula:—

$$V = W \times 22400 \div 32 \text{ where}$$

V = volume of oxygen at 0°C and 760 mm. pressure.

W = weight of oxygen absorbed.

This very simple formula gives the volume directly, and shows the great advantage of using gravimetric methods of analysis over the volumetric methods as used by Lamplough and Hill, and Winmill.

The calculated results of all the experiments have been assembled and are shown in Table No. XLIV, p. 145, but curves showing the relation between temperature and time have been drawn for each experiment,

<sup>1</sup> In the majority of the tests made in this particular investigation the coal actually lost weight owing to the loss of moisture, etc., exceeding the absorption of oxygen. In these cases the "increase in weight" would be a minus quantity and the absorption of oxygen would therefore be less than the sum of the three items evolved.

and will be explained and discussed in detail before going into a more general discussion of the results as a whole. By temperature is meant the difference of temperature between the incoming and outgoing gases in the coal container.

It should be noted that the experiments are numbered to follow those made by Billington, thus Cameron's first is numbered V and his seventh XI.

#### *Experiments V and VI.*

The curves Fig. 40 show the results of the first two experiments with the final apparatus. Both were run as nearly as possible under identical conditions; the first one on a sample of coal from the Barnsley seam at Tankersley, and the second on coal from the Silkstone seam, Normanton, England. The gases used were thoroughly dry and the bath temperature  $80^{\circ}\text{C}$ . The Barnsley coal on analysis contained 0.45% sulphur and the Silkstone coal 0.26%, both being low sulphur coals.

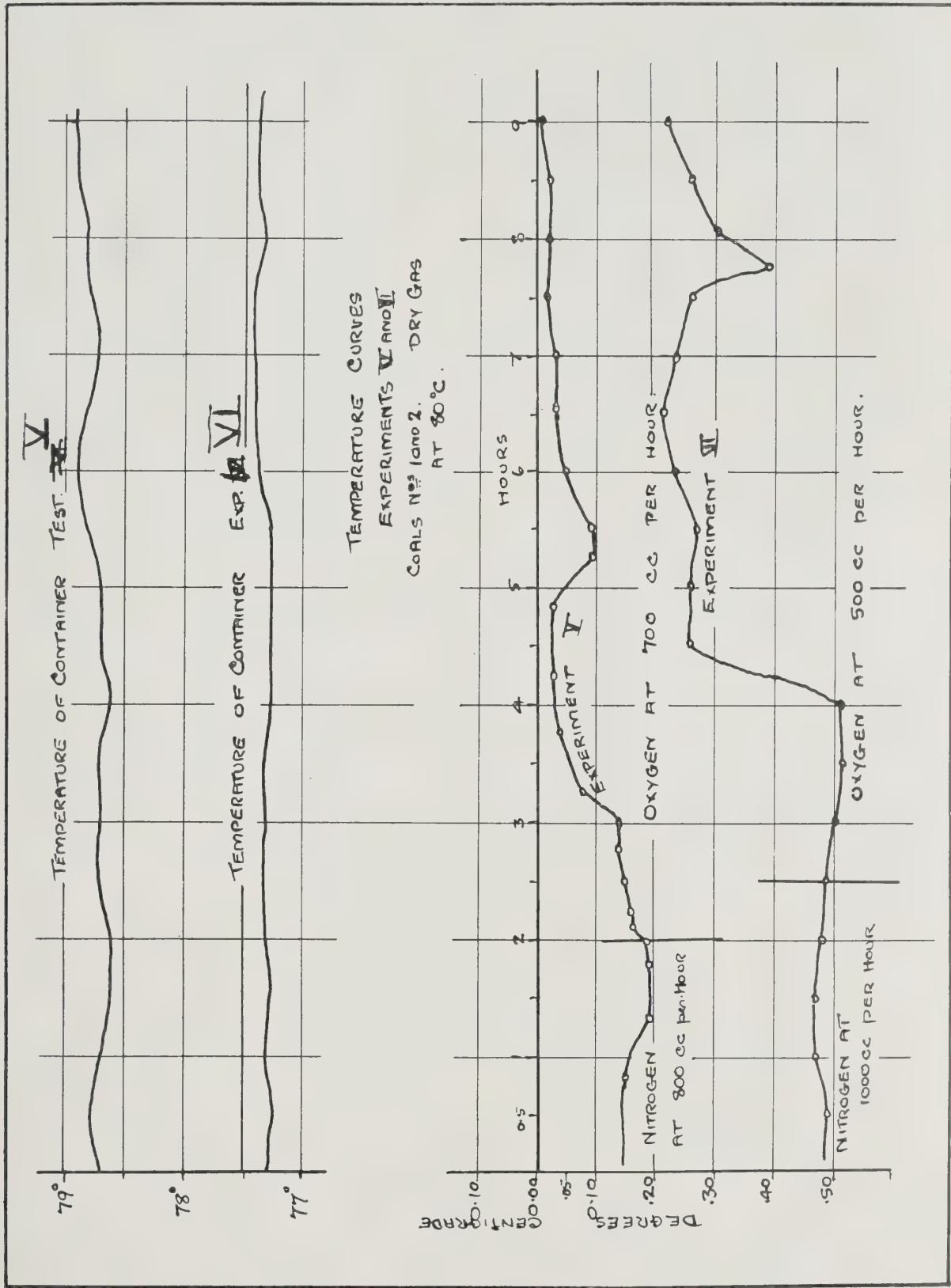
The curves show the striking similarity of the results obtained. Both coals started at a temperature slightly cooler than the incoming gas and at no time did they rise above the temperature of the gas. About two hours after the oxygen had been admitted the coals had reached a point of maximum temperature, and from there on each curve approximates a straight line. A maximum rise of  $0.18^{\circ}\text{C}$ . on oxygen as compared with nitrogen was obtained in experiment V, and of  $0.29^{\circ}\text{C}$ . in experiment VI. This greater rise in the second case is probably to be accounted for by the fact that in experiment VI the coal was subjected to a slower rate of flow of oxygen and less heat was carried off by the gas. The absorption results shown in Table XLIV, p. 145, tend to bear out this opinion.

#### *Experiment VII.*

This experiment was run on the same coal as experiment VI and under the same conditions, with the exception that the gas was first saturated with water vapour. The curve Fig. 41, p. 138, shows the temperature results obtained. It was found that the presence of the moisture rendered it practically impossible to establish temperature equilibrium while the nitrogen was passing, and after running for some hours without getting a perfectly uniform temperature the attempt to do so was abandoned and oxygen was turned on. The results obtained are very characteristic and show clearly the effect of moisture upon the temperature rise in oxygen. Owing to certain peculiarities in the running conditions of this experiment the calculated oxygen absorption as shown in Table XLIV, p. 145, is not very reliable, but is given as at least showing the order of the amounts absorbed. From the results of this and other experiments there seems to be no doubt that the presence of a small amount of moisture greatly increases the activity of the absorption reaction and consequently the heat evolution.

The temperature results of these three experiments on similar coals show, as would be expected, that the increase of temperature is inversely

proportional to the rate of flow of gas so long as enough of the latter is supplied, and as the amounts of oxygen supplied were greatly in excess of that needed for absorption, the temperature differences obtained were

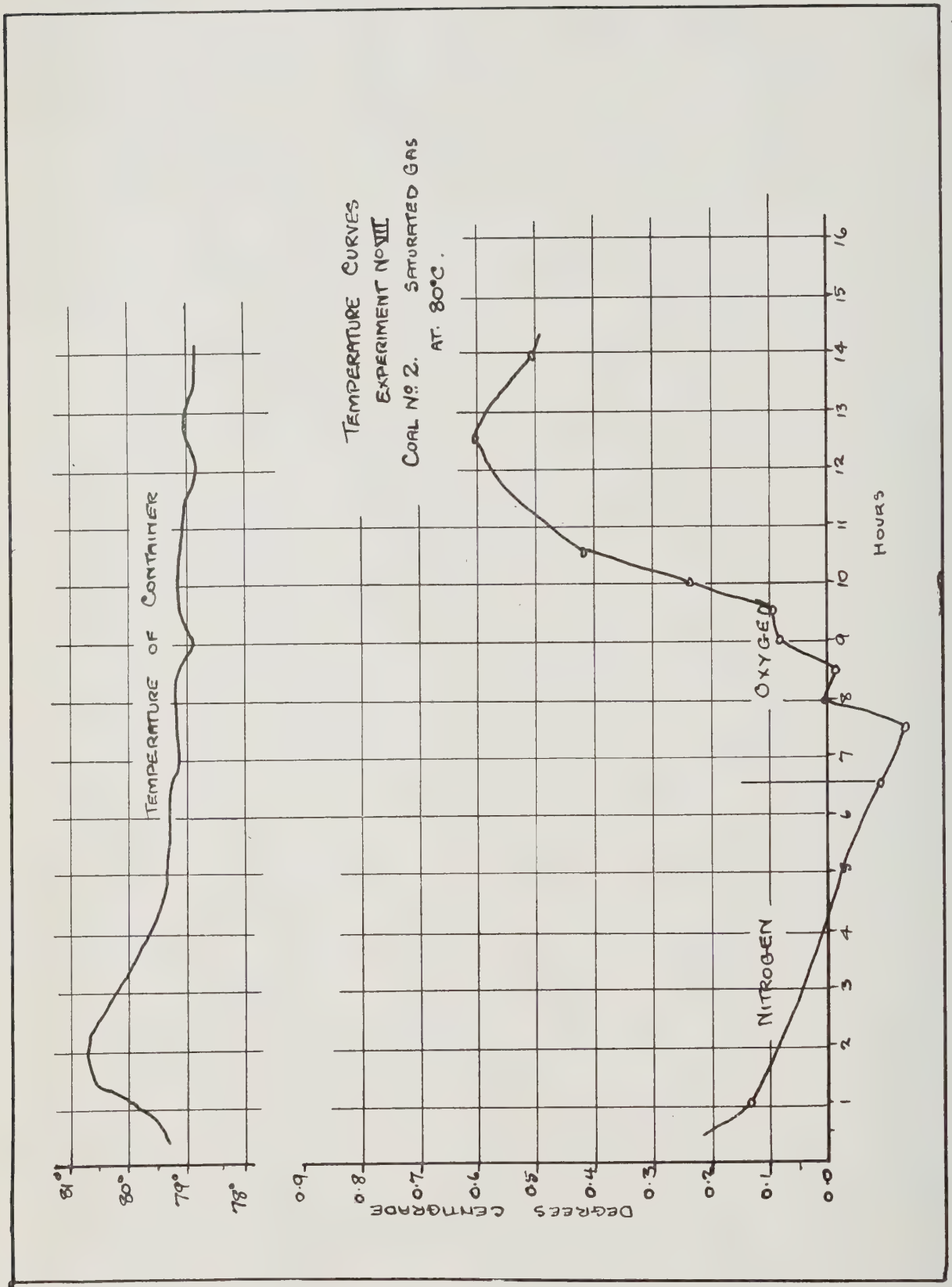


(Porter and Cameron.)

Fig. 40. Graphic record for experiments V and VI.

therefore of a very small order. It was therefore decided that in the future experiments means must be devised for giving an exceedingly slow rate of flow for the oxygen. For this purpose the apparatus shown in Fig. 38

(B) was designed by Dr. MacIntosh. It was inserted between the oxygen cylinder and the first absorption bottle of the purifying train (1, Fig. 34A)



(Porter and Cameron.)

Fig. 41. Graphic record for experiment VII.

and consists of a graduated bottle A connected by a syphon and T-piece to an open Winchester B. The third arm of the T-piece is connected through a pinch cock to a tank of water arranged to give a constant head.

A by-pass from the oxygen cylinder is arranged so that the apparatus may be swept out clean with oxygen direct from the cylinder.

The two-litre bottle being filled with distilled water, cocks 1 and 5 are closed, and oxygen from the cylinder allowed to flow into the bottle causing the water to syphon over to the Winchester. When sufficient oxygen has been collected the cylinder valve 4 is closed, the level of the water in the Winchester raised to the same level as that of the water in the graduated bottle, and cock 2 closed. In this way the oxygen in the graduated bottle is at atmospheric pressure. Then by opening cock 5, and regulating the flow of water through cock 1, any desired rate of flow of the gas can be obtained.

### *Experiment VIII.*

The coal from the Normanton Silkstone seam was again used for this experiment which was a duplication of experiment VII, except that the above described apparatus was used, and it was made solely to find out what effect a reduction in the quantity of the oxygen passing through the coal has upon temperature rise. In this experiment the total amount of oxygen passed was less than 900 c.c. during the sixteen hours of the experiment, whereas in experiment VII the gas was flowing at the rate of 400 c.c. per hour. The curve Fig. 42 shows clearly the results obtained. A comparison with curve Fig. 41 for experiment VII shows how greatly the temperature rise is influenced by the rate of flow of the oxygen.

### *Experiment IX.*

This experiment was the same as experiment VIII, except that dry gas was used. It was, therefore, a duplication of experiment VI using the improved oxygen control. The temperature rise is shown in curve Fig. 43. By comparison with the previous curves it may be noted that the rise obtained is greater than that obtained for either dry or saturated gas with a high velocity flow, but not so great as that shown in experiment VIII with a saturated gas and the same velocity flow.

These last four experiments show clearly two things:—

(1) That, as would be expected, the rise in temperature with oxygen is dependent upon and varies inversely as the rate of flow of the gas so long as the supply suffices for oxidation.

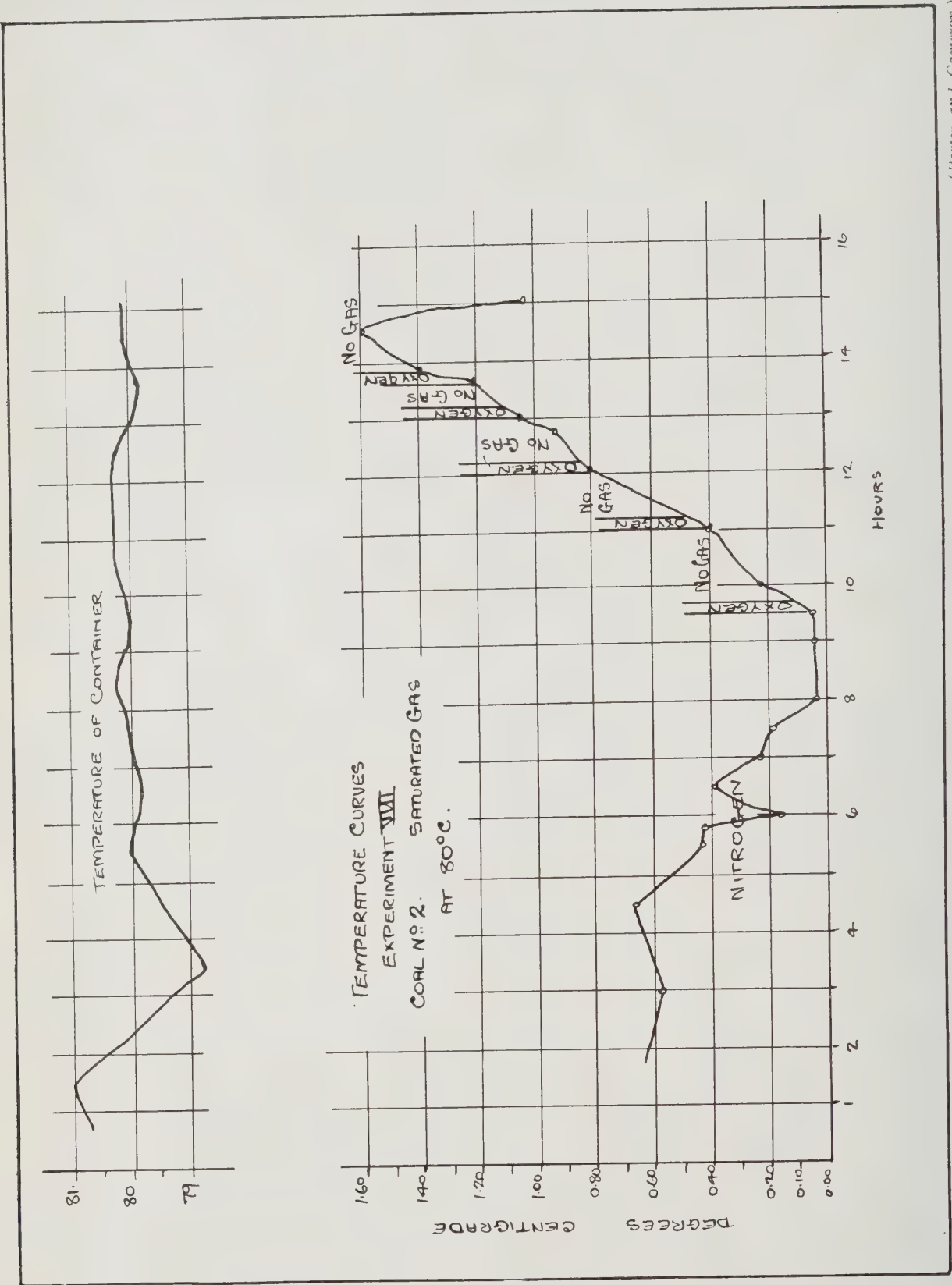
(2) That the presence of a small amount of moisture materially increases the evolution of heat due to the absorption of oxygen by the coal.

Moreover, the coal being very low in sulphur (0·26%) the experiments show<sup>1</sup> that the moisture does not play its part solely by oxidation of pyrite or other sulphur compounds present, but is a direct aid to the absorption of the oxygen by the coal itself and the consequent production of heat.

<sup>1</sup> See conclusion 3, p. 146.

Experiment X.

The coal used for this experiment, and for the one following was from the Cage Pit seam of the Acadia Coal Company, Stellarton, Nova Scotia.

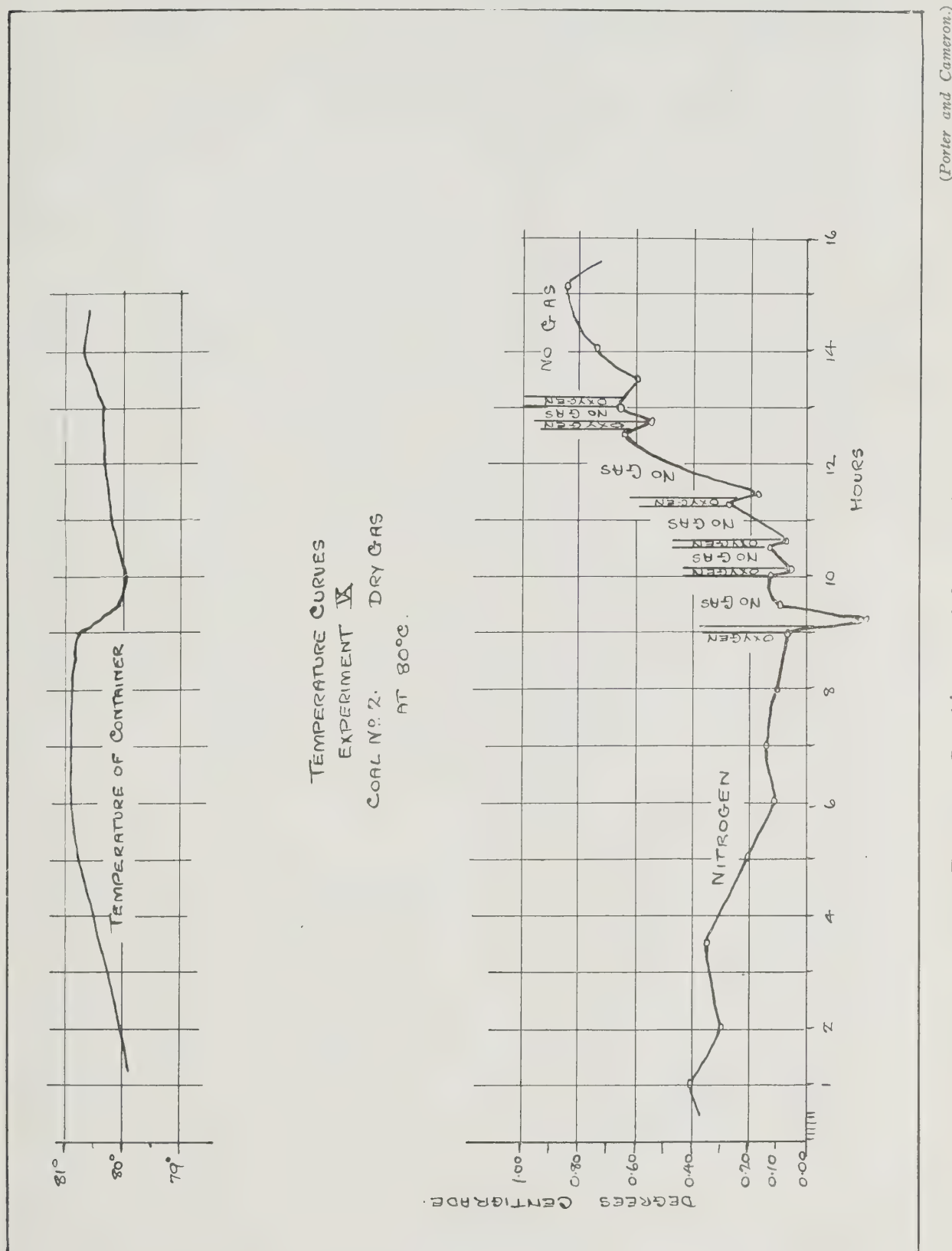


(Porter and Cameron.)

FIG. 42. Graphic record for experiment VIII.

The experiment was run with dry gas and as nearly as possible under the same conditions as the previous ones. The temperature rise with oxygen

is shown in curve Fig. 44. The total amount of oxygen passed during the experiment was less than 1000 c.c. over a period of eight hours. The bath surrounding the coal container and therefore the coal itself was main-



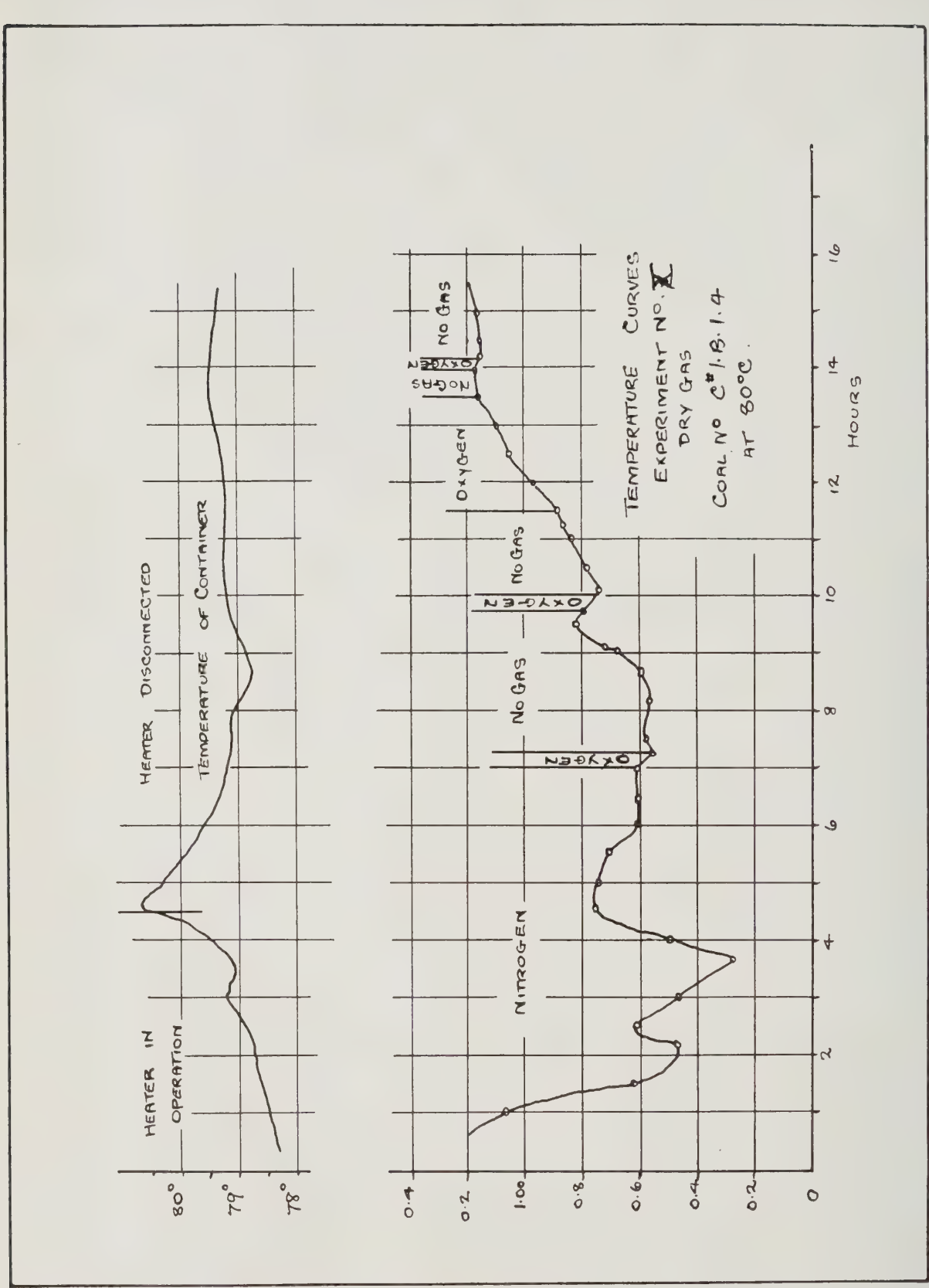
(Porter and Cameron.)

FIG. 43. Graphic record for experiment IX.

tained throughout the experiment at a temperature of  $0.6^{\circ}\text{C}.$  above that of the incoming gas and a maximum temperature rise of  $0.6^{\circ}\text{C}.$  was obtained when oxygen was passed.

Experiment XI.

This, the last experiment was run on the same coal as experiment X, and under identical conditions with the exception that saturated gas

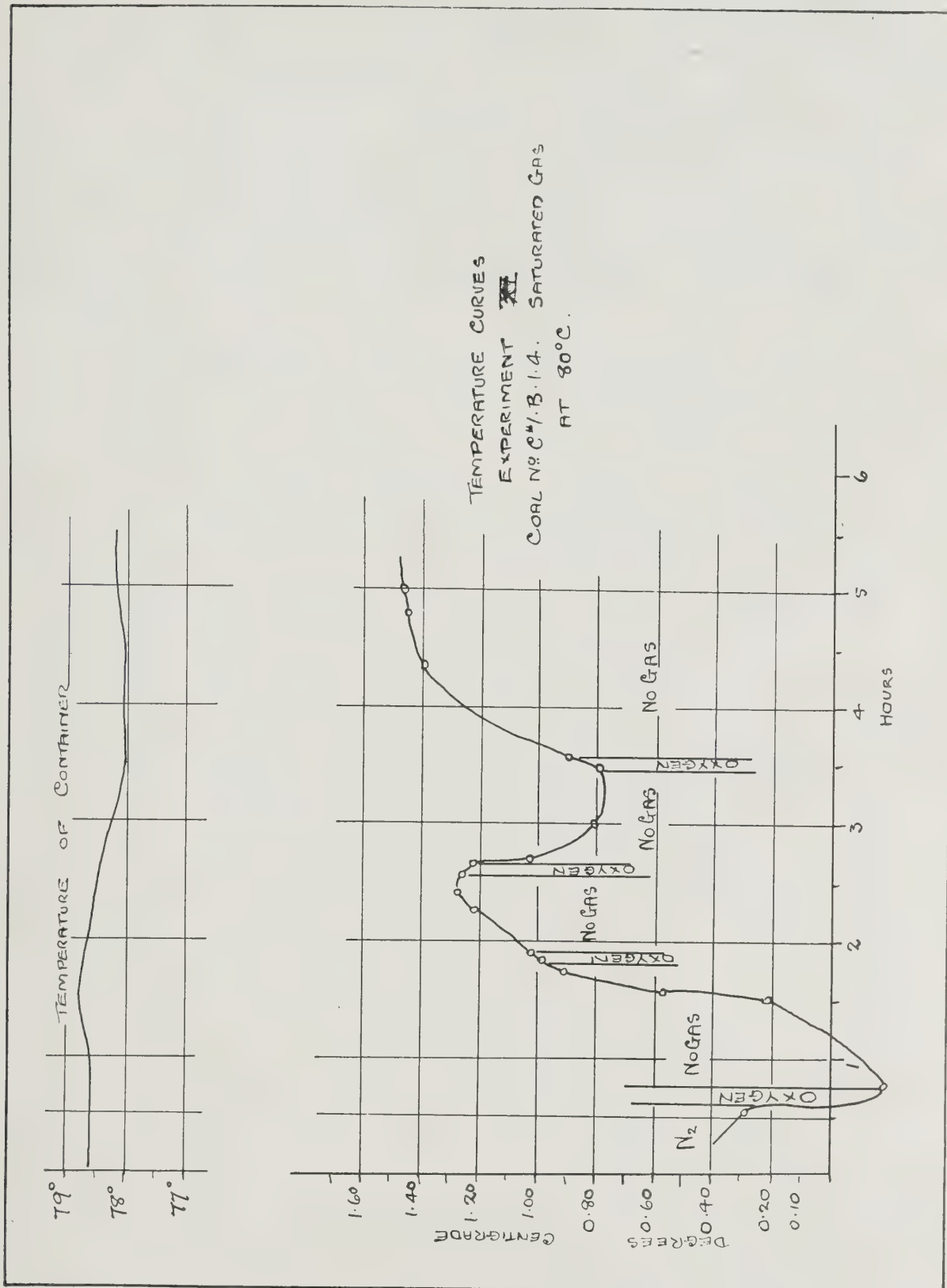


(Porter and Cameron.)

Fig. 44. Graphic record for experiment X.

was used. As in the previous "wet tests" no serious attempt was made to obtain temperature equilibrium while the nitrogen passed, but as soon as

a fairly constant condition was obtained the oxygen was turned on. The curve Fig. 45 shows the results obtained. Comparison with the curve for experiment IX shows that these results are very similar to those ob-



(Porter and Cameron.)

FIG. 45. Graphic record for experiment XI.

tained with the English coal. In this experiment the maximum temperature rise for the eight hours with oxygen is 1.2°C. an increase of 0.6°C. above that obtained with dry gas.

Another point of interest brought out by the various curves is that when oxygen is admitted even in very small quantities the temperature tends first to drop slightly and then to rise above the starting point. Moreover as soon as the oxygen in direct contact with the coal has all been absorbed the temperature begins immediately to drop again and will not rise until sometime after more oxygen has been applied.

### *The Calculated Results.*

The results obtained from the absorption train for all coals are shown in Table XLIV, p. 145. A study of this table clearly brings forth the fact that the rate of absorption by the coals experimented with depends upon the presence of some moisture, and is influenced by the rate at which oxygen passes through it.

That the first condition holds is shown by comparing the results of experiment VIII with IX, and experiment XI with X. In both of these pairs of experiments we find that the one in which saturated gas has been used has shown, by quite an amount, an increase in the absorption of oxygen by the coal in spite of the fact that in each case the passing of gas has been continued for an appreciably longer time in the dry than in the wet condition. It will, however, be shown later that these experiments must not be interpreted as showing that "wet" coal oxidizes faster than "dry."

For evidence of the second statement let us consider experiments VI and IX. Here we have the same coal subjected to as nearly as possible the same conditions, except a change in the rate of flow of oxygen, and we find that in IX with a low velocity of flow over a period of 6 hours the absorption has amounted to 3.69 c.c. per gramme of coal, while in VI with a fairly high flow the absorption for  $6\frac{1}{2}$  hours is appreciably less, being only 3.55 c.c. per gramme of coal.<sup>1</sup> The same result is even more apparent if we compare experiments VII and VIII, but as mentioned before there were certain difficulties encountered in VII which make it somewhat unreliable. The difference here, however, is so great that even allowing for possible errors it would appear that the same deduction could be made as is shown by experiments VI and IX.

### *Summary of Conclusions.*

It is of course well understood that no general conclusions can reasonably be drawn from so limited a number of experiments, but on the other hand it is thought that the experiments show certain conditions which appear to govern, to a certain extent, at least, the absorption of oxygen by coal and the consequent production of heat. These are set forth below:—

1. Oxidation depends largely upon the presence of moisture. With absolutely dry gas and almost absolutely dry coal some oxidation does

<sup>1</sup> Mr. Cameron is quite right in stating that his experiments apparently support this second deduction, and there is no doubt whatsoever that an excessive oxygen supply, as pointed out elsewhere, by keeping down temperature does actually keep down oxidation. It is, however, open to question that the very small decrease in temperature noted by Mr. Cameron as resulting from the excess of oxygen in his earlier experiments, could have had even the small effect on the rate of oxidation which his experiments would seem to show.

TABLE XLIV.  
**Summary of Records, Experiments V-XI.**  
(*Porter and Cameron*)

Experiment No.	Coal No.	Weight of coal taken gram.	Condition of gas.	Average flow of O <sub>2</sub> per hr. c.c.	Time in oxygen hours.	H <sub>2</sub> O evolved gram.	CO <sub>2</sub> evolved gram.	Hydro carbons evolved gram.	Oxygen absorbed gram.	Oxygen absorbed per gram. coal in c.c. at N.T.&P.	Oxygen absorbed per gram. coal in c.c. at N.T.&P.	Final wt. of coal gram.
V.....	1	40.0240	dry	700	7	0.3506	0.0933	0.0454	0.2502	175.14	4.25	39.7849
VI.....	2	43.6204	dry	500	6½	0.3165	0.0143	0.1272	0.2220	155.40	3.55	43.3844
VII.....	2	38.6400	wet	400	6	0.1400	0.0457	0.0142	0.1261	98.27	2.54	38.5662
VIII.....	2	37.0210	wet	50	5½	—	0.0272	0.0615	0.3171	221.97	6.00	37.2494
IX.....	2	42.9360	dry	50	6	0.4911	0.0238	0.0159	0.2265	158.55	3.69	42.6317
X.....	3	45.9960	dry	100	8	0.3166	0.0226	0.0026	0.1813	126.91	2.49	45.8355
XI.....	3	43.6080	wet	100	5	0.0293	0.0128	0.0122	0.4885	332.0	7.60	44.9422

Analysis for Sulphur:—

Coal No. 1.—Barnsley Seam, Tankersley, England.....	0.45%
Coal No. 2.—Silkstone Seam, Normanton, England.....	0.26%
Coal No. C 1. B. 1.4 Cage Pit seam, Stellarton, N.S.....	0.90%

take place, but it is clear that moisture greatly facilitates the reaction. Too much moisture will undoubtedly, however, hinder the oxidation and consequent production of heat, and it must be made quite clear that nothing in the experiments goes to indicate that "wet" coal oxidizes more rapidly than "dry" using these terms in the ordinary commercial sense. The wet tests just tabulated were really "dry" in the sense that the coal had been dried to above the boiling point, and the only moisture admitted was that of air saturated by passing through water. The total amount of moisture was therefore actually much lower than in any industrial dry coal storage. On the other hand the dry tests as conducted above involve an almost absolute exclusion of moisture: a condition quite impossible except in an elaborate laboratory experiment.

2. The absorption of oxygen by the coal and the consequent production of heat is apparently dependent upon, and to a certain extent proportional to the rate of flow of the oxidizing gas, i.e., too much oxygen or air, as well as too little, checking the action.

3. No exact information is obtainable as to how much of the oxygen, if any, went into combination with the sulphur of the coal, but the samples are all low in sulphur and No. 2 particularly has very little of this impurity, and calculation will show that even if all of the sulphur in the samples had been oxidized, which is of course an enormously exaggerated assumption<sup>1</sup>—the absorption of oxygen could not have been accounted for. In view of the work done by other experimenters on this subject it is probable that even in the "wet" tests, the oxygen was mainly absorbed by the resins and humus bodies which are known to form an appreciable part of the coals in question.

In conclusion it may be said that the experiments are but a small part of what will have to be done before the whole matter is cleared up. Much interesting work is yet to be done on pyritic coals and pyrite, with a view to finding out the true effect of this substance in the oxidation of such coals, and similarly pure hydrocarbons, resins, etc., as contained in coal and allied substances such as peat, etc., will have to be studied. It is hoped, however, that the above report will prove of some value, not only through its actual results of experiment, but also through its description of apparatus and methods.

**Parr and Francis**<sup>2</sup> experimented on the absorption of oxygen by coal at still higher temperatures than those employed by Porter and Cameron.

The apparatus used by them is shown in Fig. 46.

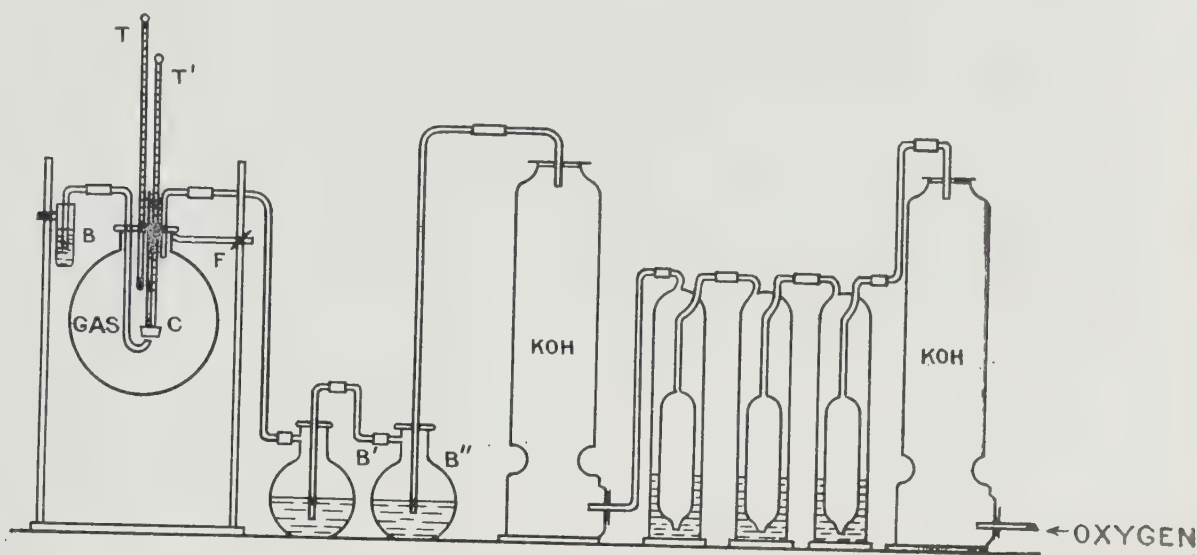
It consists of two towers filled with solid potassium hydroxide, and three wash bottles partially filled with a 50 per cent potassium hydroxide solution. That this solution thoroughly removed any traces of carbon dioxide which may have been contained in the oxygen, was proved by means of solutions of barium hydroxide in the two small flasks B' and B''. A round 1500 cc Jena flask F, served as a heating chamber, a nickel calorimeter capsule, C, for holding the material to be tested was firmly fixed in a loop of heavy iron wire and suspended in the flask. Two thermometers were used, one T, to indicate the temperature

<sup>1</sup> See pp. 42-43 ante.

<sup>2</sup> Univ. of Illinois. Eng. Expt. Sta. Bull. 24, 1908.

of the gas (oxygen), and the other  $T'$  was immersed in the coal within the capsule. The exit tube led the products into a test tube, B, containing a freshly prepared solution of barium hydroxide.

Normally it would be expected that the temperature of the surrounding gas would be slightly higher than that of the coal, the loss by convection and poor conductivity being shown by a slightly lower reading of the thermometer embedded in the coal. It is evident therefore, that any relative rise in temperature, as shown by the thermometer  $T^1$ , would be due to chemical activity within the capsule.



(Redrawn from Parr and Francis.)

FIG. 46. Oxygen absorption apparatus

**Operation.** The method of operation was as follows: Two grams of coal were placed in the nickel capsule and the apparatus adjusted as described. Oxygen was then admitted at the rate of approximately 150 bubbles per minute. The flask, F, was uniformly heated with a constantly moving Bunsen flame and readings of both thermometers were recorded every minute. The first appearance of carbon dioxide was noted in the test solution, B. This test tube was changed with sufficient frequency to indicate whether or not the evolution of carbon dioxide was continuous.

The temperatures shown by these two thermometers were plotted, and some of the curves obtained are reproduced below from the paper by Parr and Francis. The continuous line in each shows the temperature of the gas, while the dotted line shows the temperature of the coal in the capsule. In most cases there was a slight evolution of carbon dioxide at about  $30^\circ$ , but this ceased and did not begin again until about  $125^\circ$ . This first carbon dioxide is inferred to have been merely occluded gas. For convenience in charting this was omitted. This coal for Figs. 47, 48, and 51, contained:—

Moisture.....	6.53 per cent.
Ash.....	7.76 "
Volatile matter.....	33.86 "
Fixed carbon.....	51.85 "
Sulphur.....	2.10 "

The coal used in Fig. 47 was a sample of Williamson county, Illinois, Carterville coal in a finely pulverized form. At the point indicated by the first cross (x) or  $125^{\circ}$ , there was a positive appearance of carbon dioxide, which continued until a temperature of  $155^{\circ}$  was reached, when the chemical activity became so great as to cause a much more positive evolution of carbon dioxide and a very rapid rise of the thermometer  $T^1$ . At  $160^{\circ}$  as represented by the delta, the coal showed the presence of fire and thermometer observations could no longer be taken.

Fig. 48 shows a repetition of the above test except that the coal used was buckwheat size. Carbon dioxide first appeared at  $112^{\circ}$  and the more copious evolution started at  $147^{\circ}$ . This rapid evolution continued over a much longer space and a red glow was not visible in the coal until the temperature was  $258^{\circ}$ . This shows that oxidation proceeds much more rapidly with finely divided coal than with lump coal.

Fig. 49 represents a similar experiment on a sample of Taylorville, Illinois, coal in the powdered condition. The appearance of carbon dioxide was first detected at a temperature of  $153^{\circ}$  C and at the same point the two curves cross. At a temperature of  $157^{\circ}$  C the coal was on fire. In this experiment no carbon dioxide was evolved at the lower temperatures,  $120^{\circ}$  to  $130^{\circ}$  as in the case of the other coals examined. The kindling temperature is practically the same as that at which oxidation begins, as judged by the evolution of carbon dioxide.

Fig. 50 represents a similar experiment in which powdered Pittsburgh gas coal was used. The figure shows that the temperature at which fire appeared was slightly higher than with the powdered bituminous coal of Fig. 47. "This suggests that the oxidation of hydrogen may also have a part in the chemical reactions involved as being perhaps, more readily available in coals of the strictly bituminous type."

A number of tests were also made, using air instead of oxygen. One set of results is reproduced (Fig. 51). They are for the same coal as was used in the experiments whose results are given in Figs. 47 and 48. It will be seen that the results are not essentially different from those obtained when oxygen was used. As would be expected, the activity of the oxidation is decreased so that the appearance of carbon dioxide was at  $135^{\circ}$  instead of at or about  $120^{\circ}$ . The voluminous appearance of  $\text{CO}_2$  and the crossing of the lines occur at  $165^{\circ}$  instead of between  $140^{\circ}$  and  $150^{\circ}$ . At about  $200^{\circ}$  the external heat was withdrawn for a few minutes, the oxidation temperature dropped back in a similar manner. At  $280^{\circ}$ , however, the action had become entirely independent of external heating.

Apparently we have here an example of a type of combustion which occurs at a temperature far below the ignition point, and still is self-supporting and would be continuous with an adequate air supply.

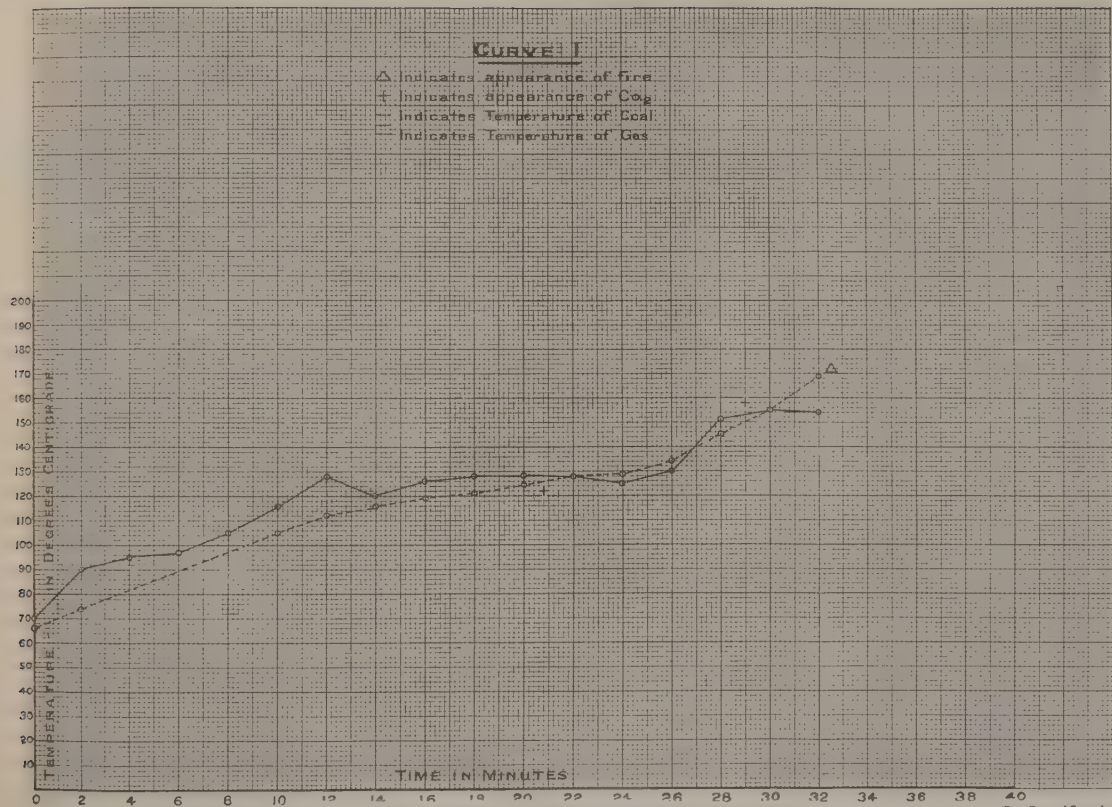


FIG. 47. Absorption of oxygen by powdered Carterville coal in atmosphere of oxygen (8).

(From Parr and Francis)



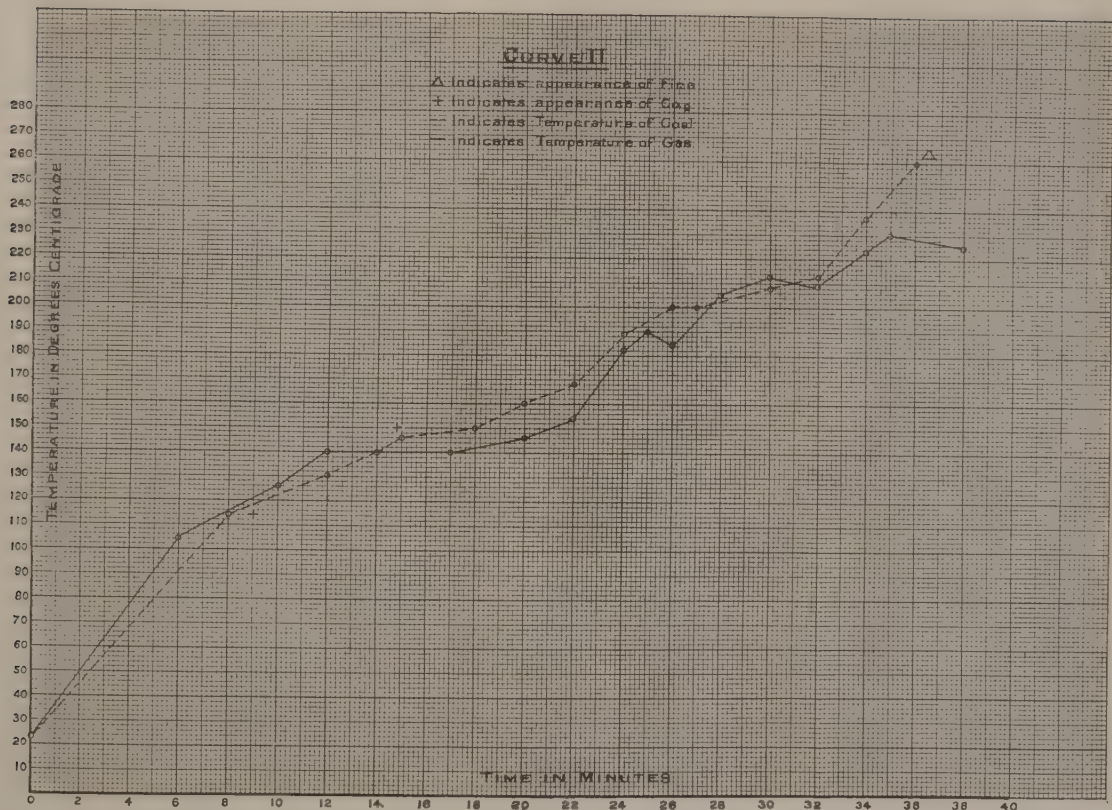


FIG. 48. Absorption of oxygen by buckwheat size Carterville coal in atmosphere of oxygen( $O_2$ ).

(From Parr and Prouty)



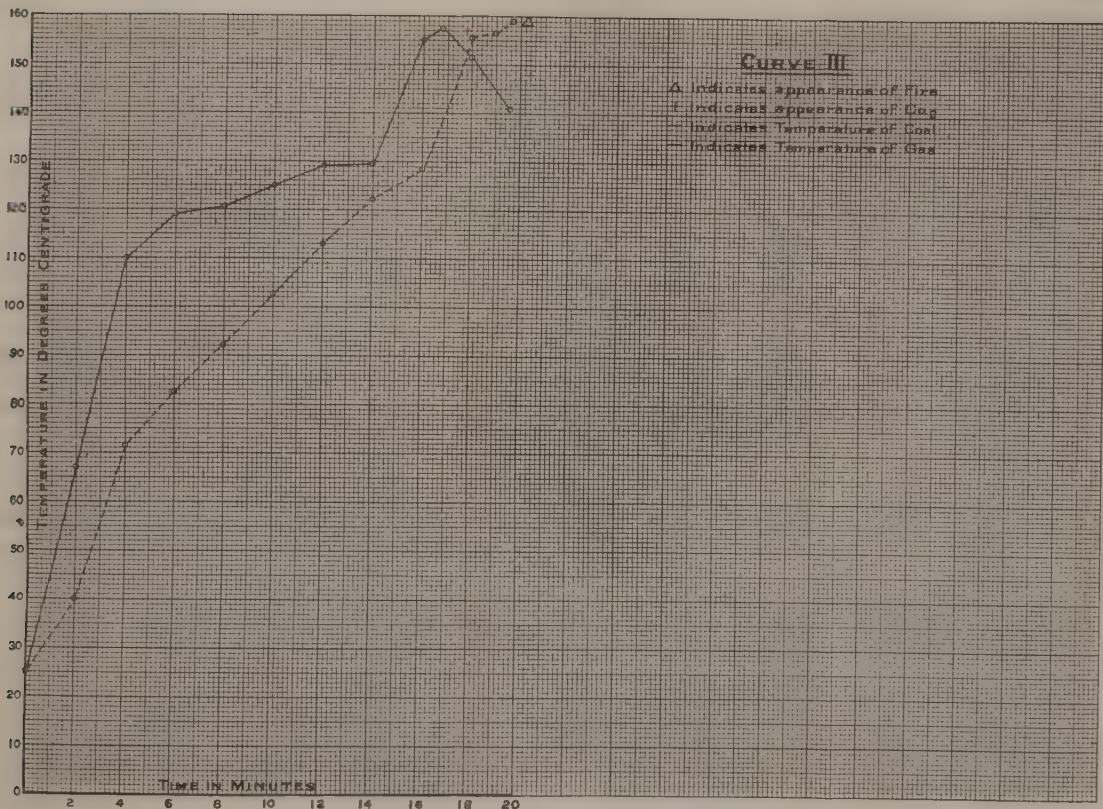
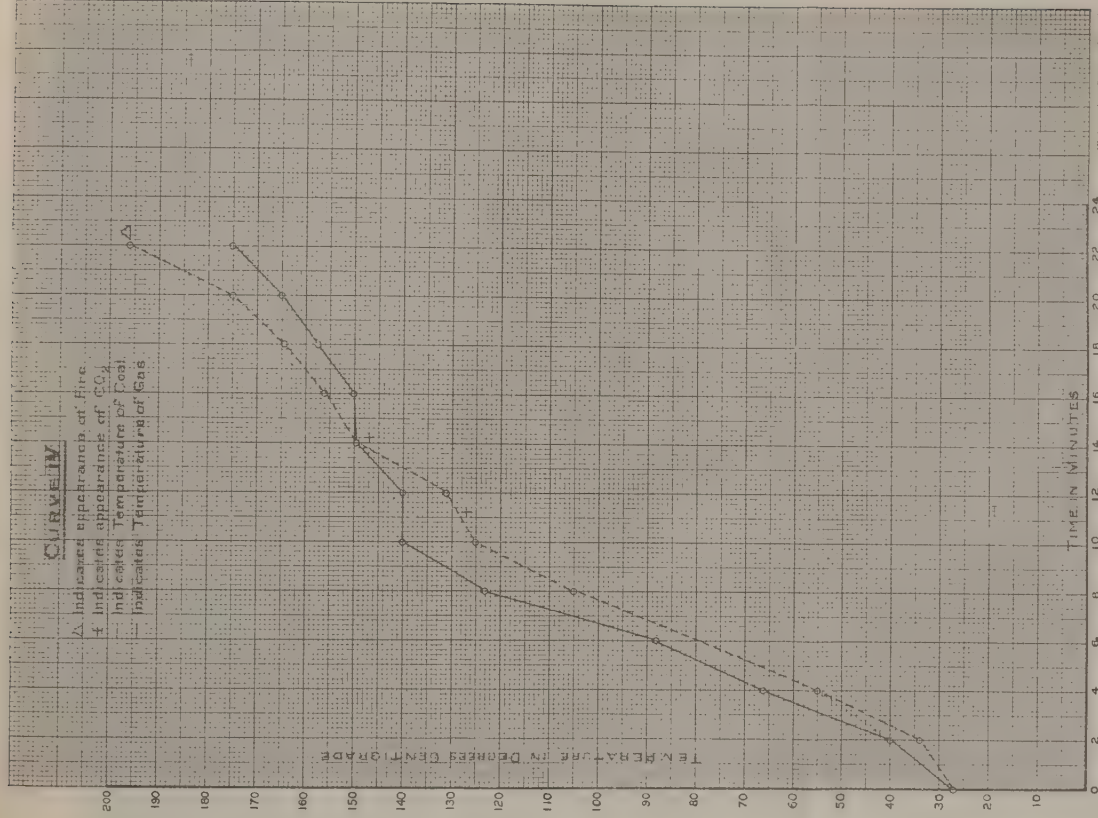


FIG 49. Absorption of oxygen by powdered Taylorville coal in atmosphere of oxygen (11).

(From Parr and Francis)





(Revised from Part and I, Vol. 1)

FIG. 50. Absorption of oxygen by powdered Pittsburgh gas coal in atmosphere of oxygen.



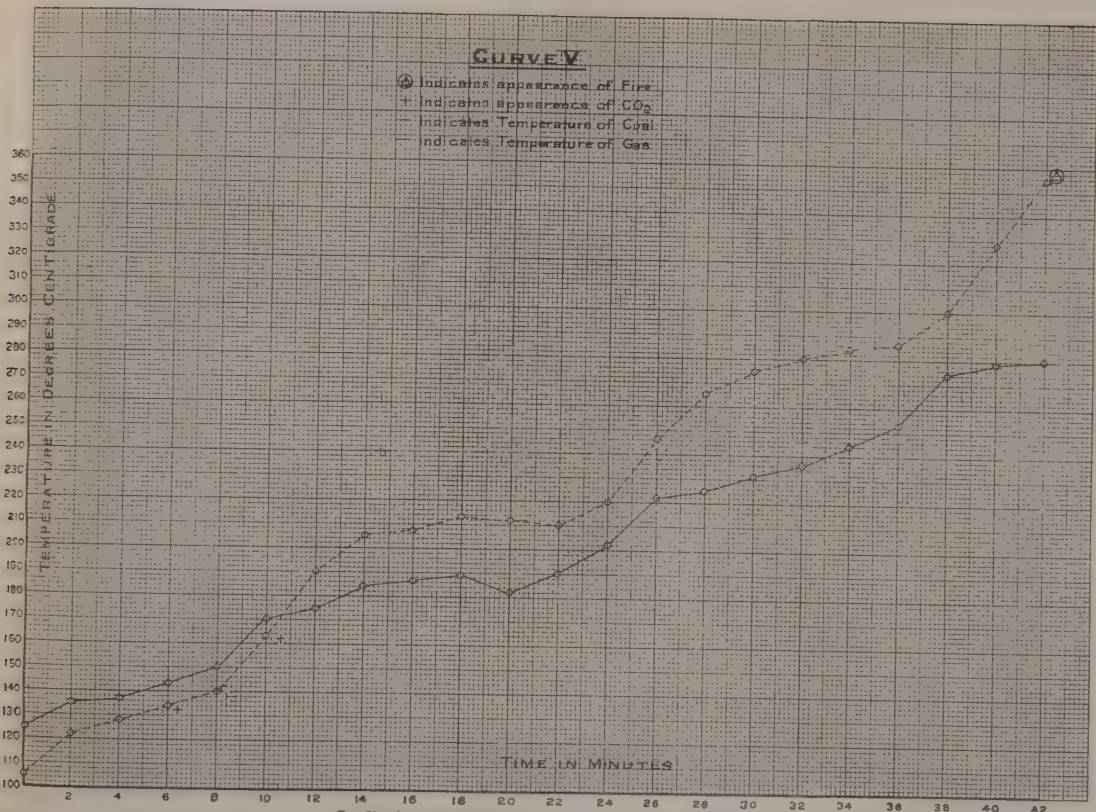


FIG. 51. Absorption of oxygen by powdered Cartersville coal in air (15).

(From Parr and Brandt)



## CHAPTER VI.

## THE PREVENTION OF FIRE IN STORED COAL.

The prevention of fire and even of serious deterioration of coal in storage is a matter of such great practical importance that it has engaged the serious attention both of Governments and private individuals for many years.

It is necessary to store very large quantities of fuel at all of the more important naval bases and at all industrial centres, and ordinarily these stores are in the form of piles of considerable height and of large extent completely exposed to the weather; but it has long been known that the majority of coals cannot safely be so stored in tropical climates, and that many coals are unsafe in large piles even in temperate lands.

The practical method of meeting the difficulty, so far as tropical stores are concerned, has been to use anthracite coals only, or when this has been impossible, to limit the size and particularly the depth of the storage piles, and to shovel the pile over, or otherwise ventilate and cool it whenever heating begins. Either of these expedients makes the coal very costly, and it has often been pointed out that any coal could be safely stored under water, either in large tanks and water-tight bins or actually below sea-level in docks properly constructed to contain the coal, and provided with the necessary filling and dredging appliances.

*Submerged Storage.*

The British Admiralty is more deeply concerned than any other single body in the matter of tropical storage, and it has accumulated a great mass of detailed information on the subject. Much of this information is necessarily confidential, but in general it may be said that in all cases submarine storage has been found to be effective in preventing decomposition and of course fire, but that the cost of the necessary equipment and the additional expenses in handling the coal are very considerable, added to which there are difficulties in many places from the contamination of the coal by silt, sewage, etc., contained in the water. It must also be remembered that the risk of fire is not confined to the coaling station; the coal ordinarily has to be sent out in cargo ships and later is bunkered in the ships that use it, and as submergence under these conditions is not practicable it is unsafe to attempt to use coals which heat, quite irrespective of the method of storage employed at the station. The general practice of the Admiralty is, therefore, to send out to tropical stations only such coals as have been proved to stand shipment and storage with a reasonable degree of safety, and to this end the various available coals have been carefully studied.

In more temperate climates a much wider range of coals can be safely stored, but for industrial purposes economy of handling is of great importance, therefore the piles are made as high as possible to lessen the first cost of the storage yards and cheapen handling. The result is that heating is common and fires not infrequent, and various devices have been tried such as submerged bins, ventilation channels through the coal, etc.

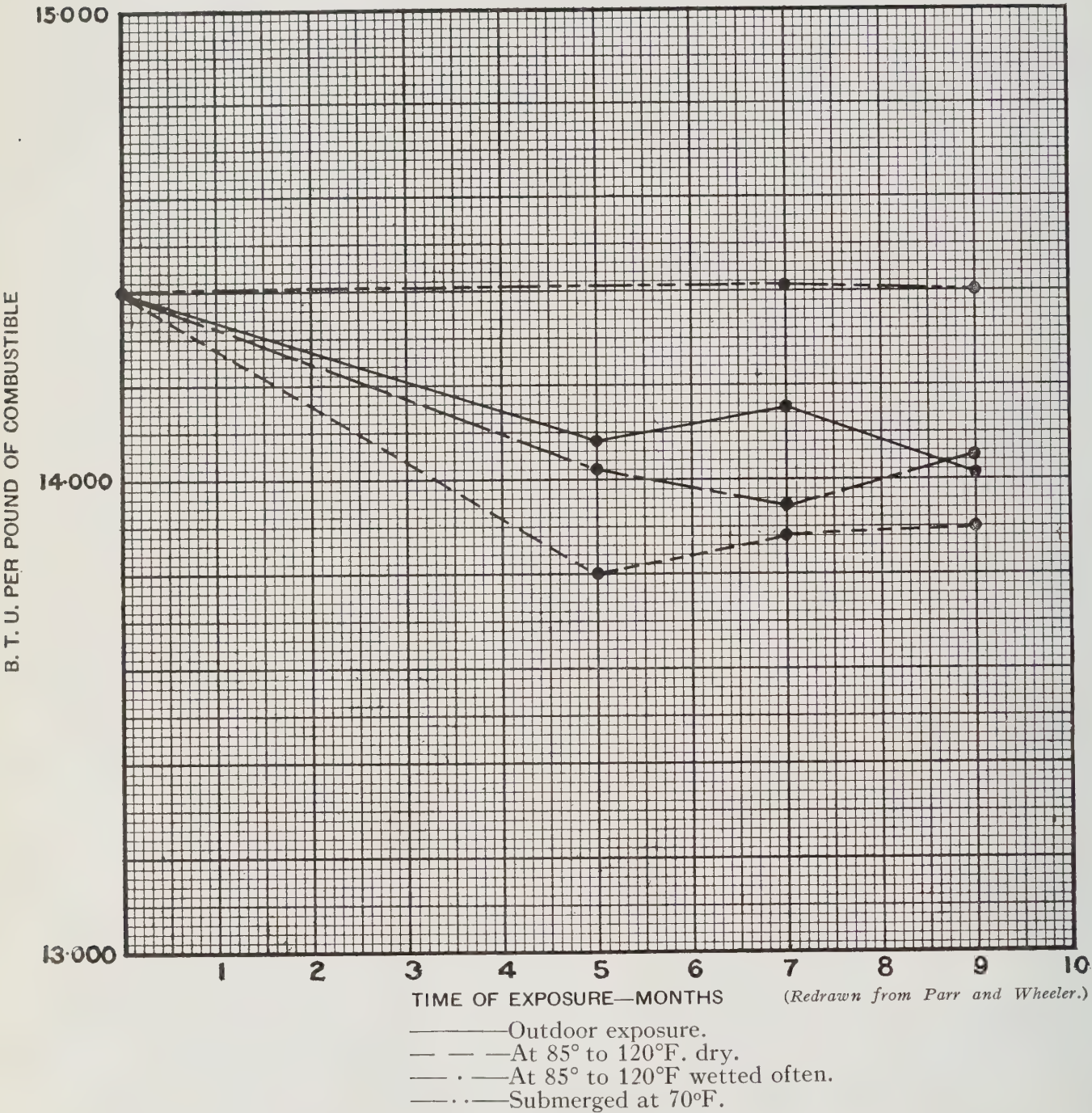


Fig. 52. Calorific power of exposed vs. submerged coal.

Some tests made by the British Admiralty<sup>1</sup> to determine the weathering losses of coal stored in the air and of coal submerged under water have been made public. In May, 1903, twenty-one tons of coal were selected from storage piles. Ten tons were stacked in heaps and covered with tar-

<sup>1</sup>Eng. News, Vol. 56, 1906, p. 17.

paulins and ten tons were placed in two-ton crates and submerged in one of the navy yard basins at Portsmouth. The remaining ton was burned carefully under a test boiler, observations being made of its calorific and evaporative qualities. The crates were taken up at intervals and the coal was tested by burning in comparison with the coal stored on dry land for the same length of time. The actual figures are not available, but it is reported that in every case the results were in favour of the submerged coal.

A test made by the Fuel Engineering Co.<sup>1</sup> of Chicago on coal stored under water for two years, and similar coal exposed to the atmosphere for two years, showed calorific values as follows:—

Submerged coal 11,937 B.Th.U., weathered coal 11,718 B.Th.U., or a difference of about 1·9 per cent. Since both samples contained 15·9 per cent of ash the two results are directly comparable.

Parr and Wheeler<sup>2</sup> refer to the storage of coal by the Western Electric Company, whose 15,000 ton concrete bins contain coal which is kept altogether submerged. This coal shows an advantage of 1·9 per cent in heating value in favour of the coal stored under water, after a period of two years. The same authors had previously<sup>3</sup> published some curves from Hamilton's experiments—Fig. 52—showing that coal stored under water for almost one year suffered no appreciable alteration.

In spite of ample evidence that submergence either in fresh or sea water not only protects coal from fire, but also retains its full heating power indefinitely, practical difficulties have thus far prevented any extended commercial use of this system, and it is doubtful whether it will ever be employed very largely for ordinary coals except perhaps at tropical naval bases; but there is undoubtedly a large field for this method of storage in the case of lignites and lignitic coals, which not only heat readily, but also disintegrate and lose a very appreciable fraction of their value on weathering. Such coals can be kept virtually intact under water, and it is probable that in the course of time it will be found commercially expedient to provide submerged stores at places where such coals can be produced or sold at much lower prices than more stable fuel. There are immense quantities of lignitic coal in many parts of the world—as for example in Alberta and Saskatchewan in central Canada; and although they have lower calorific value than bituminous coal, their geographical situation renders them the logical fuel for large areas. As a matter of fact these coals are already much used at points where a fresh and reliable supply can be secured. By suitable system of storage their use could be very greatly extended, and arrangements to this end will no doubt be made comparatively soon, unless in the meanwhile some cheaper method of preservation is developed, or we come to burning coal at the mines and transmitting its heat and power electrically or otherwise.

<sup>1</sup> Eng. News, Vol. 60, 1908, p. 729.

<sup>2</sup> "The Weathering of Coal," Bull. 38, University of Illinois Experiment Station, 1909.

<sup>3</sup> The Deterioration of Coal. Journal American Chemical Society, Vol. XXX, 1908, pp. 1027-33.

*Ordinary Storage.*

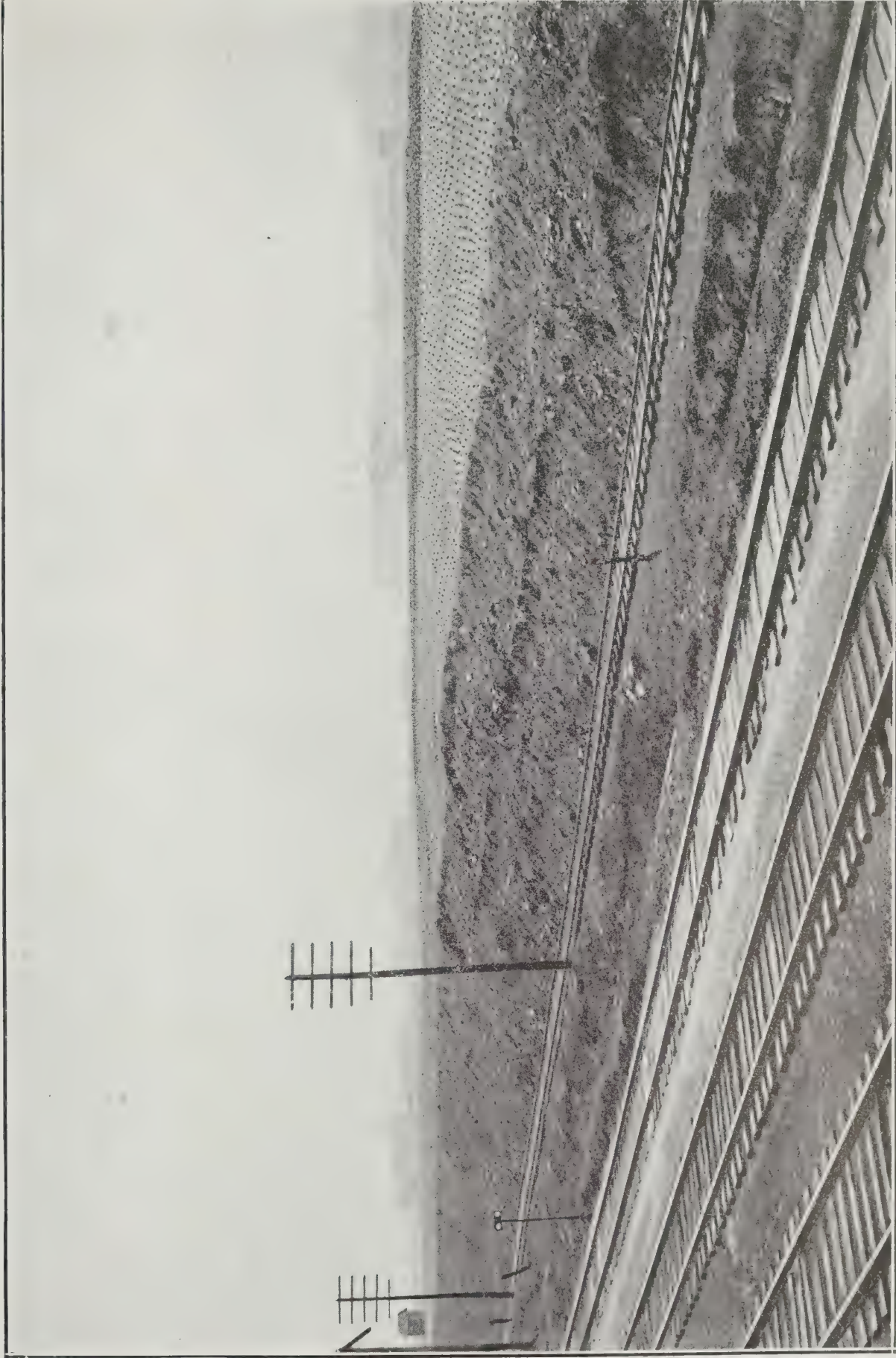
Many authorities recommend as an alternative to submergence that the coal be stored in sheds affording protection from both sun and rain. It is by no means clear that rain is harmful (see p. 27), although there is a widespread belief that it precipitates heating, but there is no doubt that exposure to the sun is dangerous at least while the pile is being made, as coal, owing to its blackness, absorbs heat rapidly, and if it is then covered by a fresh layer of coal this heat is retained and greatly accelerates subsequent oxidation. When the quantities to be stored are comparatively small or the conditions particularly severe this expedient of storing under cover is worthy of consideration; but when the quantities are large the cost of the sheds becomes a serious item, and there is usually also a considerable increase in the handling expenses owing to the increased complexity of the loading and unloading arrangements. It is therefore very unusual to have large covered storage plants except perhaps at certain tropical naval stations where cost is of secondary importance. It should, however, be noted in this connexion that enclosed storage even on a fairly large scale is frequently practised for reasons having little or nothing to do with oxidation and heating. It is quite customary to have loading bins of large capacity at railway and steamship coaling stations; but these are to enable supplies of fuel to be quickly loaded by gravity, and under ordinary conditions no one lot of coal remains long enough in such storage to run risk of heating.

In cold and wet localities it is also occasionally expedient to house coal supplies, as otherwise the fuel would freeze into a solid mass of mixed coal and ice.

When submerged storage is impracticable and the coal is piled either in sheds or in the open it is clear that the air cannot be excluded and heating is liable to occur. Provision must then be made for conducting the heat generated away from the pile. This can be done in two ways, first, by piling the coal in shallow heaps, or second, by ventilating the coal pile. It has been found by practical experience that shallow coal piles will not ignite spontaneously, the particular height to which any coal can be safely piled can, however, only be determined experimentally. The same result can be obtained in deeper piles by providing air ducts whereby the coal is so well ventilated that the supply of air is so greatly in excess of that needed for oxidation that the incoming air will keep the pile cool.

A method of storing coal and ventilating it has been developed by the **Canadian Pacific Railway**<sup>1</sup> whereby fires have been virtually eliminated. The method in general is: first to level off a triangular piece of ground so that temporary tracks may be laid upon it and a steam shovel used if desired. A track is then laid in and hopper-bottom coal cars unloaded on this track, which is then raised on the coal and the operation repeated until an embankment of considerable height is made, with an inclined track from the apex of the triangle to the main line. When a sufficient height is reached,

<sup>1</sup> See plates I, II, VI, and pp. 159-163.



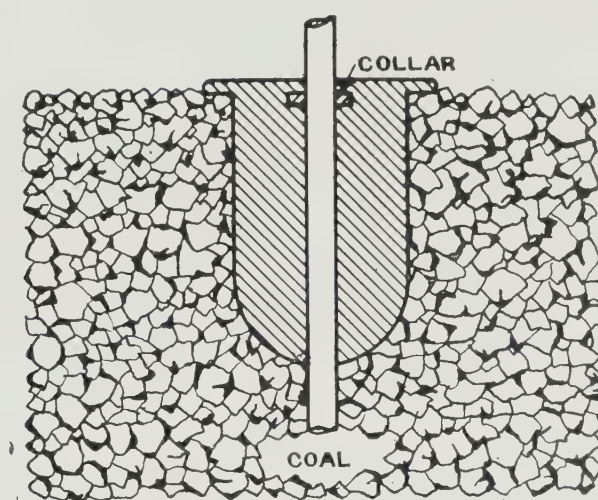
General view of storage pile at Angus.

(Porter and Brunton)



the coal is side dumped or side shovelled and the track is gradually shifted to one side and the width of the pile thus increased to any desired extent. The height of the pile on the approach increases from nothing to about 16 feet, and this latter height is maintained for the major portion of the pile.

As soon as possible after each portion of the pile reaches its full height it is ventilated by driving pointed iron rods,  $1\frac{1}{2}$ " or 2" in diameter, vertically down through it. After the rod reaches the bottom a bell-shaped collar is slipped over it and forced down about six inches into the coal, as shown in Fig. 53, p. 153. The rod is then tapped to compact the coal around it and to loosen the rod itself and both collar and rod are withdrawn. A rough funnel of tar paper is then put in the bell-shaped top of the hole to prevent pieces of coal falling in or being washed in by the rain. The walls



(Porter and Brunton.)

FIG. 53. Apparatus for ventilating storage piles.

of the lower part of the hole maintain themselves without protection, and holes driven in this way ordinarily last for many months. The distance between the holes varies somewhat with the circumstances; but generally it is about 16" from centre to centre, and the cost, which is almost wholly labour, amounts to approximately 5c. per ton.

Another method, which is frequently effective, and in certain cases economically possible, is to pile the coal in layers of about 2 feet, allowing each layer to be exposed to the air for at least two days, and if possible much longer, before it is covered by the next layer. This method is usually effective in preventing fire, if the piling is done in cool weather, but in mid-summer, particularly in hot and sunny weather, it is of doubtful value to say the least. Porter and de Hart have experimented on this method of storage, see pp. 154-159.

In order to obtain detailed information on deep storage piles a series of experiments were made by the author and his assistants, Messrs. Brunton and de Hart, on Nova Scotia coals from the Dominion Coal Company, these coals being selected because they form the main part of the ordinary fuel supply of eastern Canada. These tests were carried out under two

heads: (1) to study the storage of fresh coal at the mines; and (2) to study the behaviour of coal which had been shipped in cargo lots to Montreal and stored there.

*Porter and de Hart experiments, Glace Bay.*

The experiments at the mines were made at Glace Bay, Nova Scotia, in the summer of 1911, by Mr. J. B. de Hart working under Dr. Porter's personal direction. Four similar piles were made by dumping coal cars from a railway trestle. Each pile contained about 90 tons and was built as follows:—

Pile No. 1. The coal used was fresh "run-of-mine" from No. 4 mine of the Dominion Coal Company. (Phalen seam). It was mined the day before the pile was built, and was exactly as it came from the mine except that it became damp owing to rain, which fell during the transfer.

Pile No. 2 was made with coal from the large stock pile of the Dominion Coal Company. This coal had been mined in February and was chiefly but not wholly from the Phalen seam. This coal was also damp when piled.

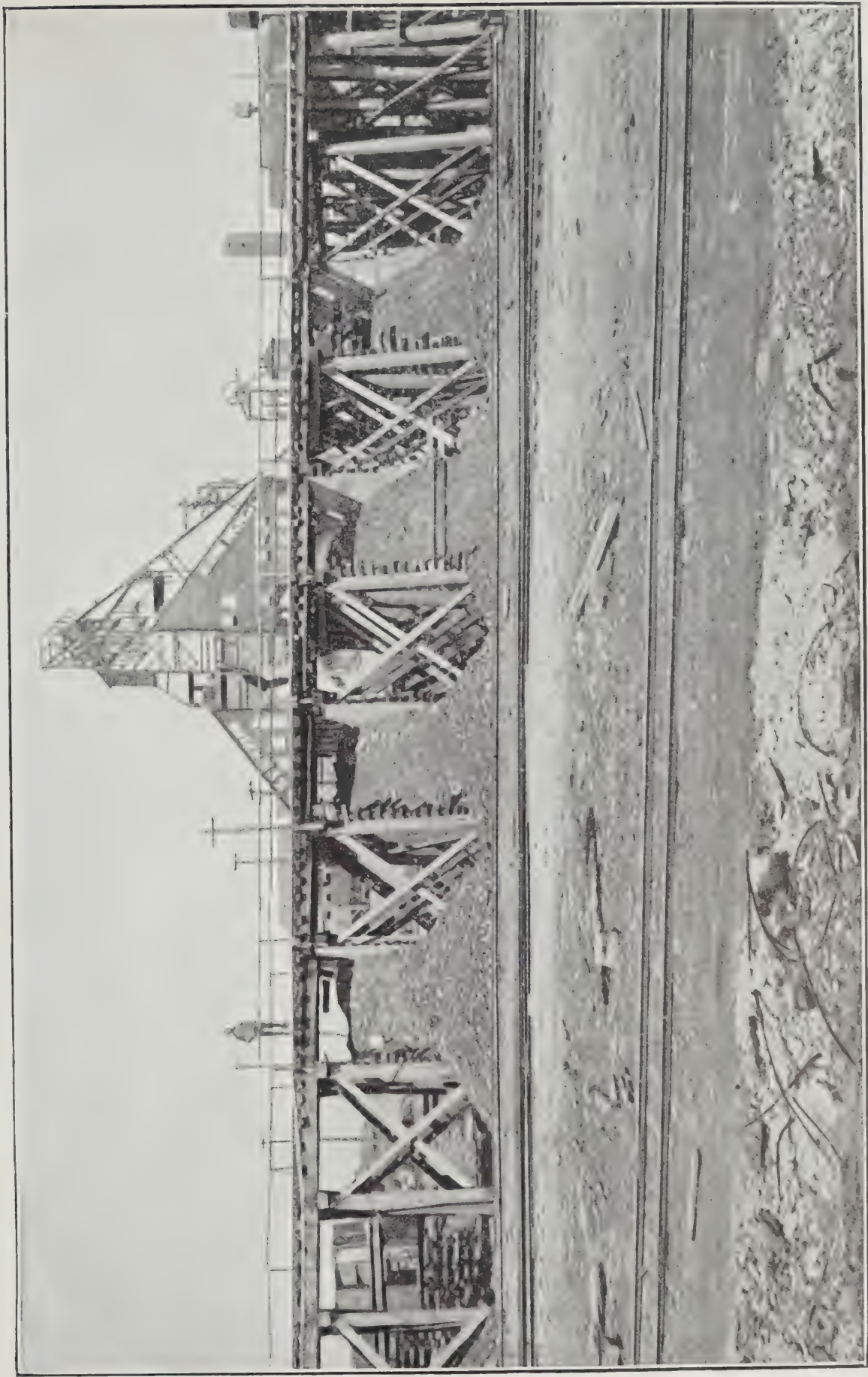
Pile No. 3 was built of two kinds of coal. First, nine or ten feet of stock coal, as in pile 2, was dumped, and on top of that five or six feet of freshly mined run of mine coal from No. 4 colliery as in pile 1. Both coals were damp.

Pile No. 4 was the same as pile No. 1 except that the coal was piled in layers about 3 to 5 feet thick, an interval of two days being left between the dumping of successive layers.

The piles were situated between successive bents of a trestle. The coal was not in contact with the wood of the trestle, however, as the bents between which the coal was dumped were boarded up and protected by galvanized iron. The location can be seen from photographs. (Plates III, IV, and V.

The method of piling the coal was by dumping it from hopper bottom cars on top of the trestle and then "trimming". In some cases the coal tailed out over the tracks at the side of the trestle and had to be held back by a low wall of planks as can be seen in the photographs above mentioned. These planks constituted the only wood in contact with the coal. The coal for piles 1 and 4 and the top half of 3 was mined on July 19, 1911. The dumping of pile No. 1 was commenced on July 20, and finished July 21. Pile No. 2 of stock was dumped on July 20. The stock coal in Pile No. 3 was dumped on July 20, and the fresh coal on July 21. Pile No. 4 was built in layers as follows: July 21, 30 tons; July 24, 15 tons; July 26, 15 tons; July 28, 15 tons; and July 31, 15 tons.

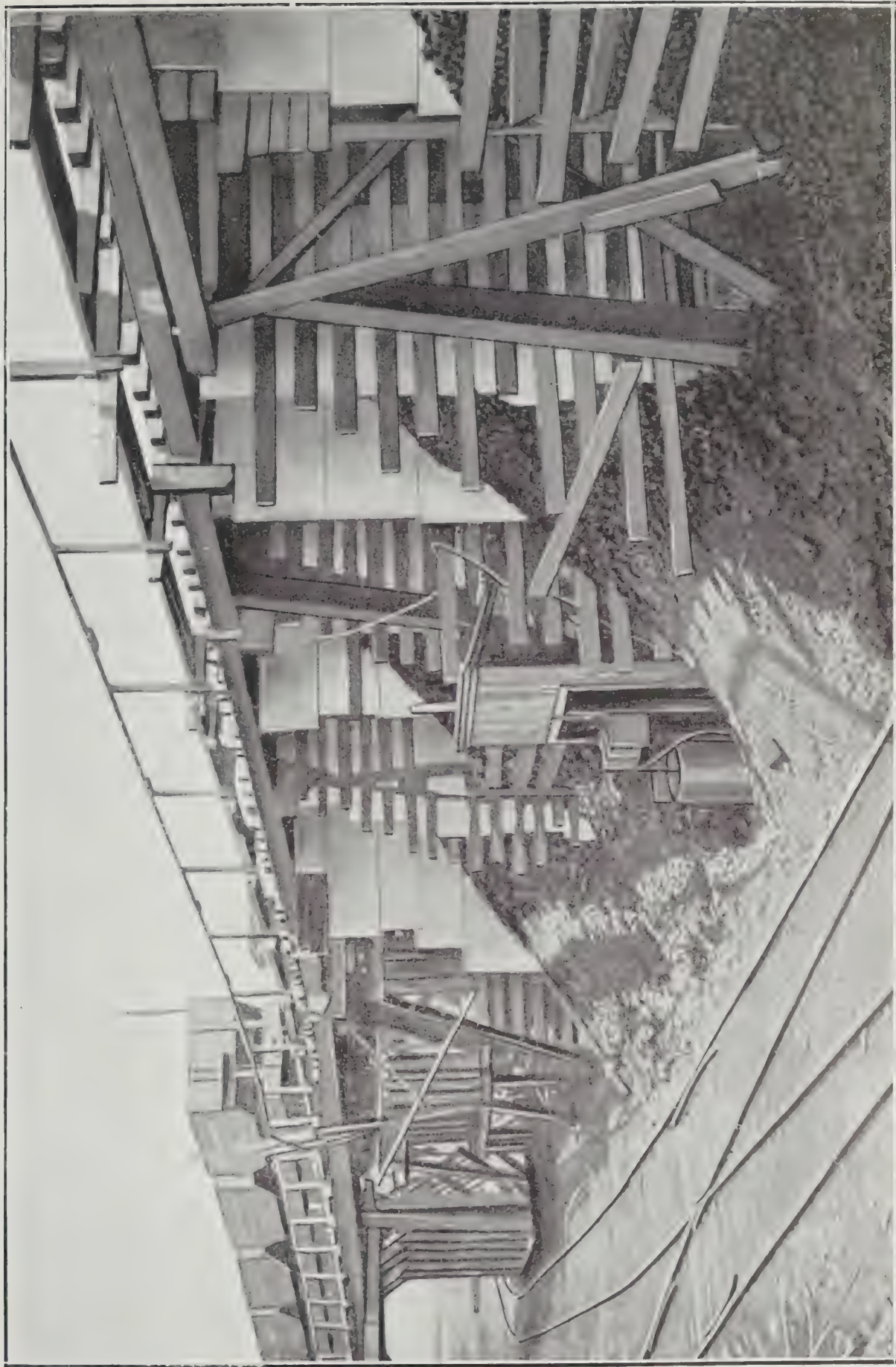
As each pile was made three  $\frac{1}{2}$  inch iron pipes were put in. They were 8 feet, 14 feet, and 20 feet long respectively. These pipes were open at the bottom and were threaded at the top and were kept closed by caps or wooden plugs. Their positions are shown in plan and elevation in Fig. 54. Two pipes (S) in the form of a U were also placed, one in pile 1, and one in pile 2. They were open at the ends which projected into the air.



(Porter and de Hart)

General view of experimental piles at Glace Bay.





General view of experimental piles at Glace Bay.

(Porter and de Hart)



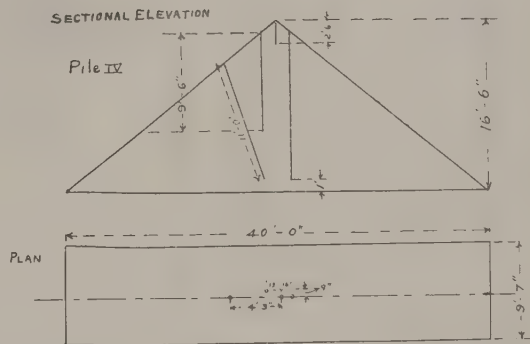
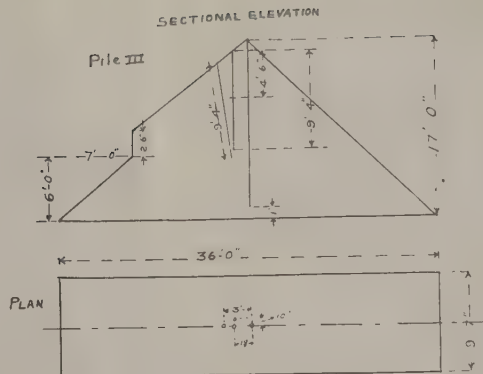
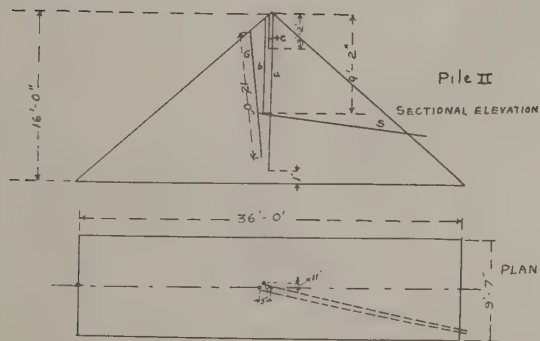
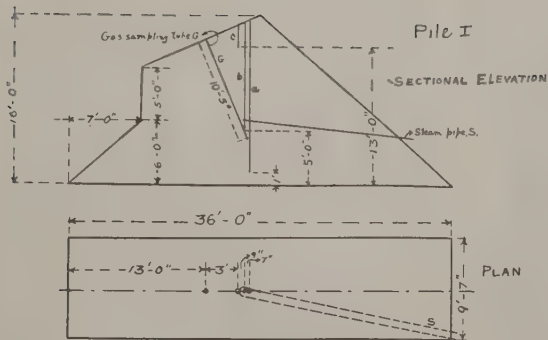


FIG. 54. Diagrams of coal piles, Glace Bay.



10  
19

TABLE XLV.  
Temperature and Pressure Readings—Glacie Bay Storage.  
(Porter and de Hart)

Date.	Relative humidity per cent.	Atmospheric temperature degrees C.	Atmospheric pressure Inches Hg:	Weather.	Temperatures (Deg. C.)											
					1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B	4C
July 20 ..	97	17.6	29.95	Cloudy	—	—	—	13.5	13.5	13.5	—	—	—	—	—	—
21	84	20.1	29.87	Fine	17.0	19.0	18.0	16.0	16.0	12.0	—	—	—	—	—	—
22.....	78	18.3	29.90	Cloudy	16.0	18.0	17.0	14.0	14.0	10.0	13.5	14.0	16.0	20.0	—	—
23	91	18.1	29.96	Showery	16.0	18.0	17.0	14.0	14.0	14.0	14.0	14.0	16.5	18.5	—	—
24	57	19.0	29.97	Fine	17.0	19.0	18.0	14.0	14.0	14.0	14.5	14.0	17.0	20.0	—	—
26	63	19.4	30.10	Fine	17.0	19.0	18.5	14.5	14.5	15.5	15.0	15.0	17.0	19.0	—	—
27.....	48	21.3	30.33	Fine	17.5	19.5	19.5	14.0	14.5	17.0	15.5	15.0	18.0	20.0	18.0	—
28	40	22.5	30.94	Fine	18.5	20.0	20.5	15.5	16.5	18.0	16.0	15.5	17.5	—	—	—
30.....	65	21.7	30.10	Fine	—	21.3	—	—	17.0	—	—	—	—	—	—	—
31.	—	19.0	—*	Cloudy	17.5	20.5	21.0	15.5	16.0	18.2	15.5	16.0	15.5	19.0	18.5	—
Aug. 3.....	63	15.8	—	Fine	18.0	20.5	22.0	15.5	17.0	18.0	15.5	17.3	19.5	21.0	19.5	—
10	63	—	—	Fine	21.0	24.8	26.0	17.5	20.5	21.5	17.5	19.0	22.5	23.5	23.0	22.5
11	—	19.1	—	Fine	—	—	—	—	—	—	—	—	—	—	—	—
13	—	16.9	—	Fine	25.0	27.0	29.0	17.0	19.0	18.0	17.5	18.5	21.5	22.0	21.5	22.0
15	64	18.7	—	Fine	25.0	28.0	30.0	17.0	20.0	17.0	17.5	18.5	21.5	23.0	22.5	23.5
16	90	18.7	—	Wet	—	—	—	—	—	—	—	—	—	—	—	—
19	90	17.5	—	Wet	25.0	28.0	32.5	19.0	20.5	16.0	17.5	19.5	20.0	23.5	22.5	24.0
20	66	14.2	—	Cloudy	—	—	—	—	—	—	—	—	—	—	—	—
24	54	16.9	—	Fine	29.0	32.0	35.0	17.5	20.0	16.5	17.0	17.0	17.0	21.5	20.5	23.5
27.....	74	15.7	—	Fine	28.0	33.0	35.5	18.0	21.0	18.0	17.5	19.0	19.0	23.5	22.0	20.5
29	96	21.5	29.79	Cloudy	30.5	33.0	37.0	19.5	22.0	19.0	19.0	21.0	20.5	25.0	24.0	27.0
31	—	14.3	30.20	Fine	—	—	—	—	—	—	—	—	—	—	—	—
Sept. 3	90	18.3	29.87	Showery	31.0	35.0	38.0	19.0	22.0	15.5	18.0	20.0	20.0	25.0	23.0	28.5
5	—	15.1	—	Fine	—	—	—	—	—	—	—	—	—	—	—	—
9	59	13.1	30.16	Fine	29.0	34.0	36.0	20.0	22.0	14.0	17.0	18.8	18.5	25.0	22.0	27.0
13.....	—	16.3	29.70	Showery	29.5	34.0	37.0	18.5	21.0	17.0	18.0	18.0	19.0	23.0	21.5	25.0
15	—	9.0	30.13	Fine	27.5	33.8	35.5	20.0	22.5	14.0	—	—	—	—	—	—

\*No barograph readings were obtained between July 30 and August 28 owing to the fact that the barograph had been sent away for repairs.



Their use will be explained later. A brass tube G,  $\frac{1}{8}$  inch internal diameter was forced to the centre of each pile after it had been completed. These brass tubes were used to draw off gas samples from the interior of the piles. All these pipes and tubes are shown in Fig. 54.

Temperatures were taken at frequent intervals in the  $\frac{1}{2}$  inch pipes. It will be well to refer to these pipes by symbols. All the long pipes will be called A, the medium pipes B, and the short pipes C. Thus the top pipe in pile 1 will be called 1C, and in pile 2, 2C, and so on. The middle pipe in pile 3 would be 3B.

The atmospheric temperature and pressure were recorded by a thermograph and barograph respectively, and the relative humidity was taken at intervals. The results of these observations, together with notes on the weather, are given in Table XLV.

The temperatures and pressures given are the average for the 24 hours obtained from the thermograph and barograph curves. All temperatures are given in degrees centigrade. The temperatures in the  $\frac{1}{2}$  inch pipes were taken by maximum recording thermometers which were let down to the bottoms of the respective holes by strings. When the temperature in the holes was less than the atmospheric temperature it was impossible to use these thermometers, hence an ordinary centigrade thermometer was employed, and was pulled up and read as rapidly as possible. The error thus introduced was probably less than one degree except in one case noted. The temperature readings have been plotted on a time base as per Figs. 55-61, p. 156, and in this way the rise of temperature can perhaps be most readily seen.

A point which is clearly shown by these figures is the fact that the coal which was piled in layers heated less than the coal which was piled quickly. Unfortunately, the coal in none of the piles heated to any great extent, and it is, therefore, impossible to tell whether piling the coal in thin layers at intervals of several days would prevent spontaneous combustion in a case where it would otherwise occur. The difference in temperature rise, however, is considerable. The maximum temperatures attained in piles 1 and 4, which were almost identical except for the length of time taken in building, were as follows:—

1A	30.8°	1B	35°	1C	38°
4A	24.3°	4B	22.75°	4C	27.5°

It seems probable, therefore, that piling the coal in layers and exposing each layer to the air would, in many cases prevent spontaneous combustion. Unfortunately in the majority of cases economic considerations prevent the adoption of this method of piling the coal, as ordinarily the pile is made by dumping the coal out of railway cars run on a track laid on the pile and shifted as the pile grows. In such cases the above method would involve a disproportionate expense for track moving. The method, however could be used without much added expense where the piles are made by an overhead travelling grab.

The higher temperature of piles which have been built quickly is probably due to the fact that absorption of oxygen and consequent heating is exceptionally rapid in the first few hours of exposure. If the coal is covered in by fresh coal at this stage it retains its heat, whereas, if it is left exposed for a longer period, the rate of oxidation decreases and the coal is free to cool off to approximately atmospheric temperatures. If, however, the pile is built in hot weather and particularly in bright sunlight, slow piling is likely to result in even greater heating than quick piling. As a matter of fact coal piled in summer and in dry, i.e., sunny weather, is found to be especially liable to give trouble.

It is interesting to note the times taken to attain the maximum temperatures. They were approximately as follows:—

TABLE XLVI.  
Dates of Maximum Temperature in Glace Bay Storage.

(Porter and de Hart)

Pipe.	Date of max. temp.	Time since comple- tion of pile.
1A.....	September 4.....	45 days
2A.....	" 17.....	59 "
3A.....	August 27.....	38 "
4A.....	September 4.....	35 "
1B.....	" 4.....	45 "
2B.....	" 17.....	59 "
3B.....	August 29.....	40 "
4B.....	" 30.....	30 "
1C.....	September 3.....	44 "
2C <sup>1</sup> .....	" 17 <sup>1</sup> .....	59 <sup>1</sup> "
3C <sup>1</sup> .....	August 28 <sup>1</sup> .....	39 <sup>1</sup> "
4C <sup>1</sup> .....	September 4 <sup>1</sup> .....	35 "

<sup>1</sup>Records too irregular to enable any smooth curve to be drawn. Probably due to some extent to the enforced use of a non-maximum thermometer.

We may say that roughly, Pile 1 reached its maximum temperature on September 4, Pile 2 on September 17, Pile 3 on August 28, and Pile 4 on September 4.

On September 16, temperatures were taken in the pipes in pile 1 every foot down. These temperatures showed the maximum temperature to be about three or four feet below the surface. The same general location had been observed by Porter and Brunton previously at Angus, and was later found to be true of a C.P.R. coal pile at Outremont. Probably above the depth of maximum heating there is too rapid radiation and ventilation to allow of the maximum temperature being attained, and below this point there is insufficient oxygen to enable the coal to oxidize freely enough to yield high temperature.

In order to determine the absorption of oxygen and evolution of methane and other gases, gas samples were drawn from the centre of the pile and analysed. The samples were sucked out through the brass tubes

# CURVES SHOWING TEMPERATURES IN PILE 1

Points on the A curve thus — ♦  
Points on the B curve thus — X  
Points on the C curve thus — ○

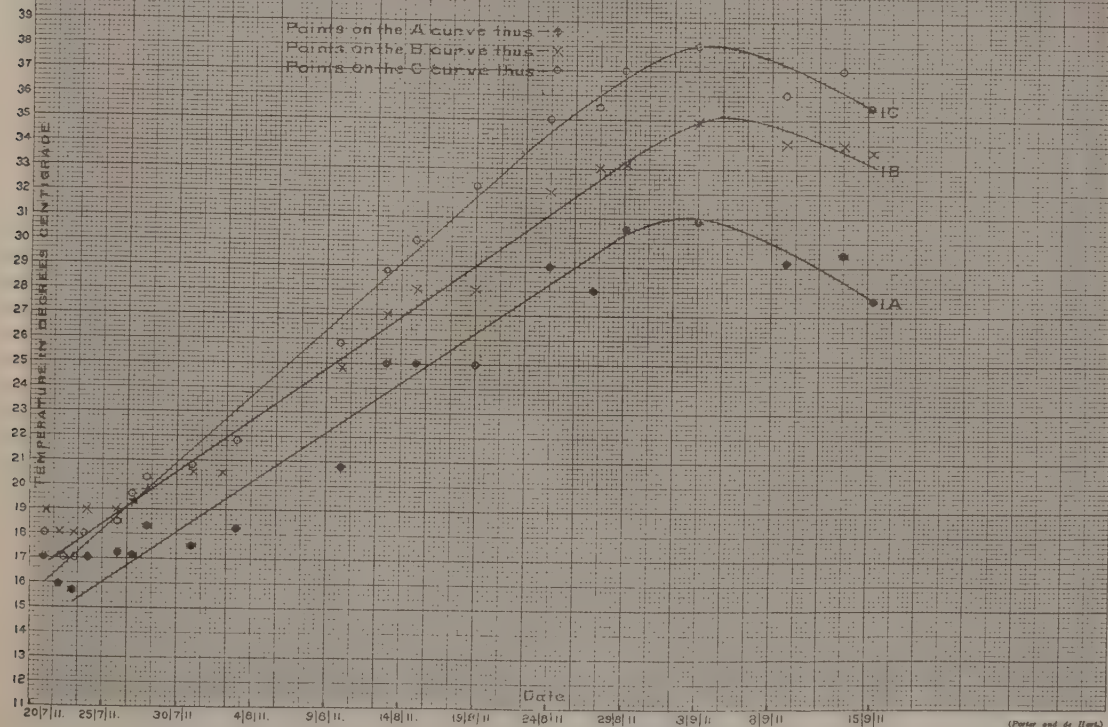


FIG. 55. Graphic record of temperature in Pile No. 1, Glace Bay, N.S.

(Porter and de Harck)



# CURVES SHOWING TEMPERATURES IN PILE 2

Points on the "A" curve thus—X

Points on the "B" curve thus—O

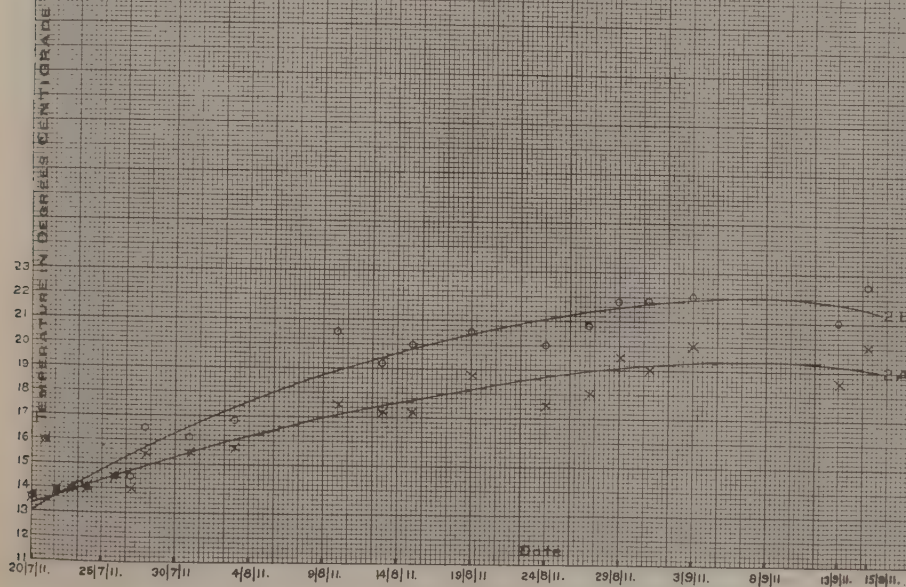


FIG. 56. Graphic record of temperature in Pile No. 2, Glace Bay, N.S.

(Porter and de Hart)



# CURVES SHOWING TEMPERATURES IN PILE 3

Points on the A curve, thus -O

Points on the B curve, thus -X

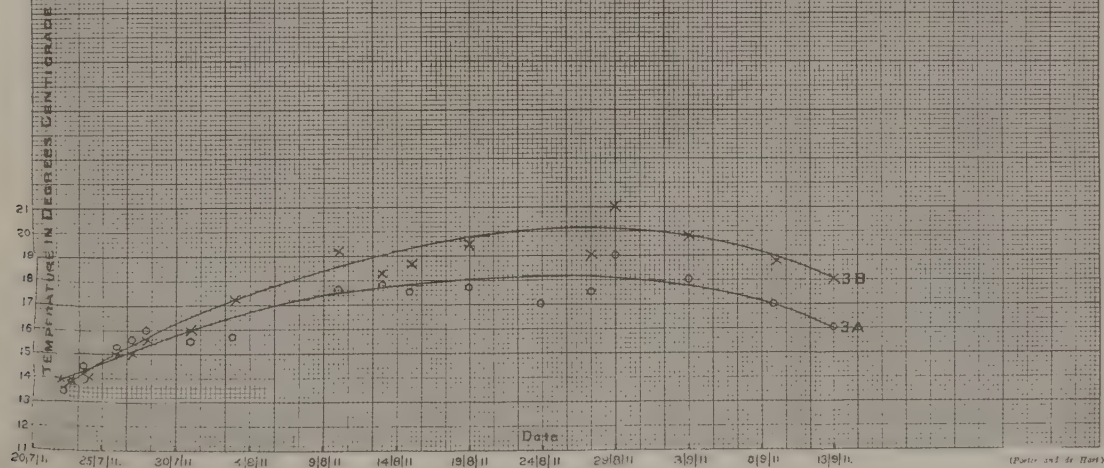


FIG. 37. Graphic record of temperature in Pile No. 3, Glace Bay, N.S.



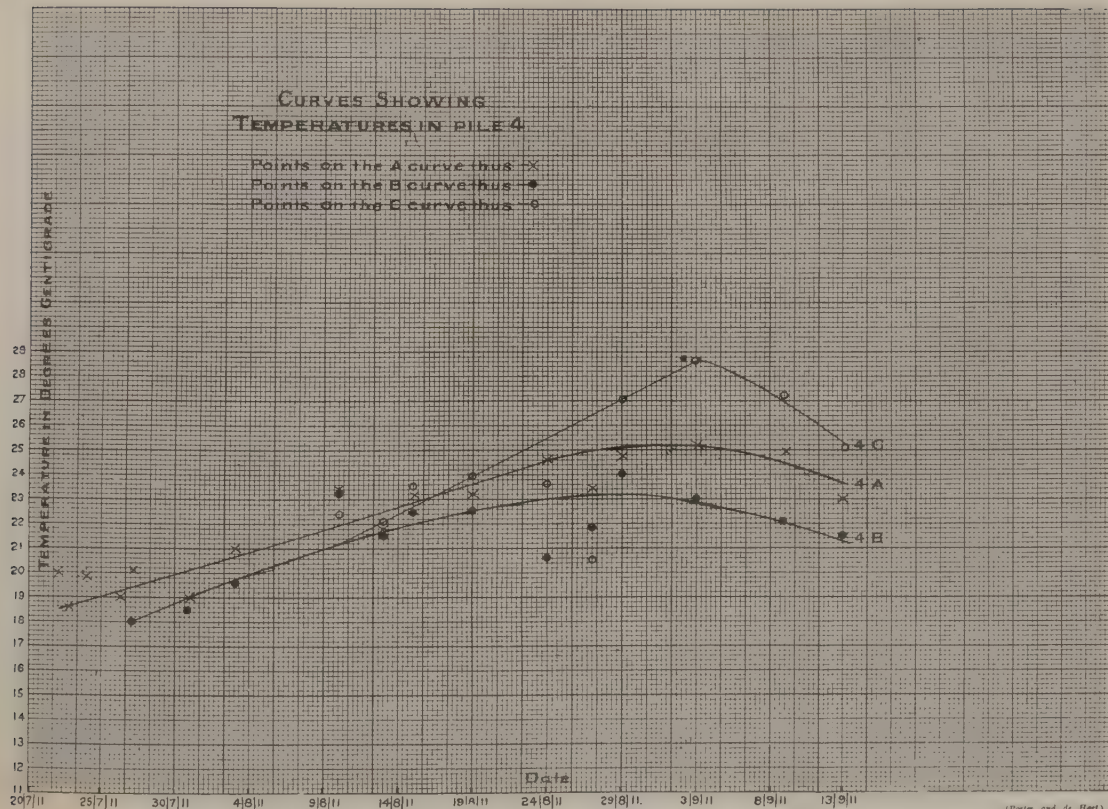


FIG. 58. Graphic record of temperature in Pile No. 4, Glace Bay, N.S.



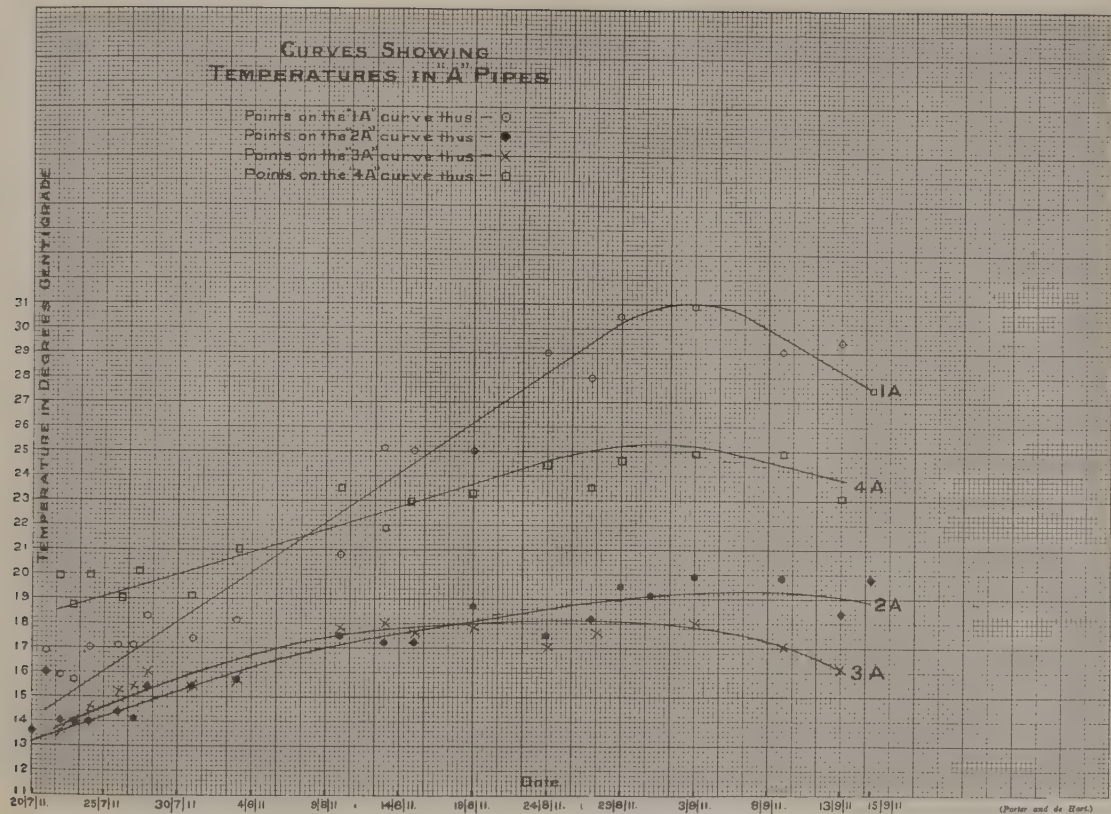


FIG. 59. Graphic record of temperature in A pipes, Glace Bay, N.S.

(Porter and de Hart.)



# CURVES SHOWING TEMPERATURES IN B PIPES

Points on the "1B" curve thus - ○  
Points on the "2B" curve thus - ●  
Points on the "3B" curve thus - ×  
Points on the "4B" curve thus - □

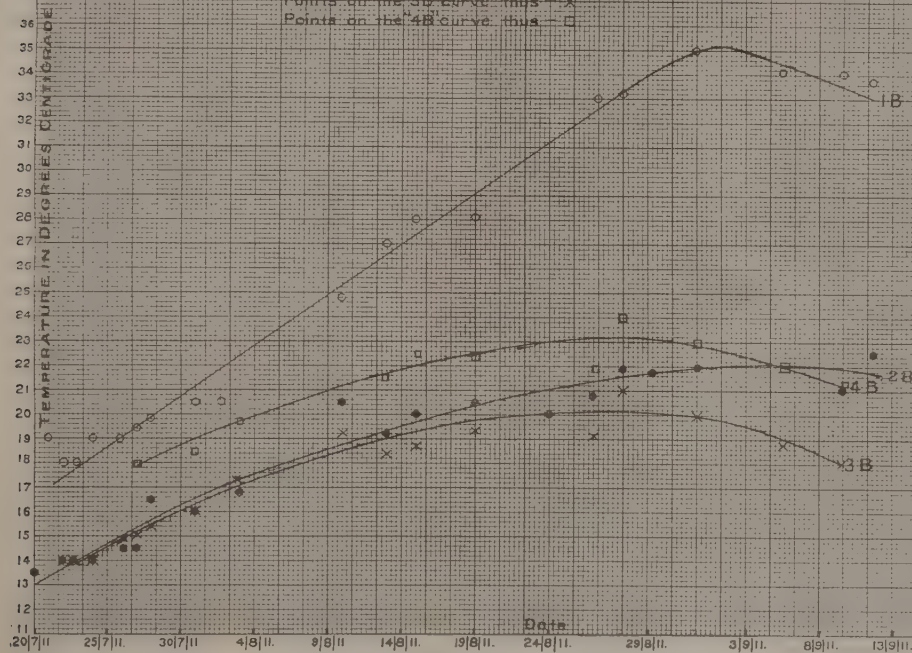


FIG. 60. Graphic record of temperature in B pipes, Glace Bay, N.S.

(Porter and de Hart)

# CURVES SHOWING TEMPERATURES IN C PIPES

Points on the 1C curve thus—○  
Points on the 4C curve thus—●

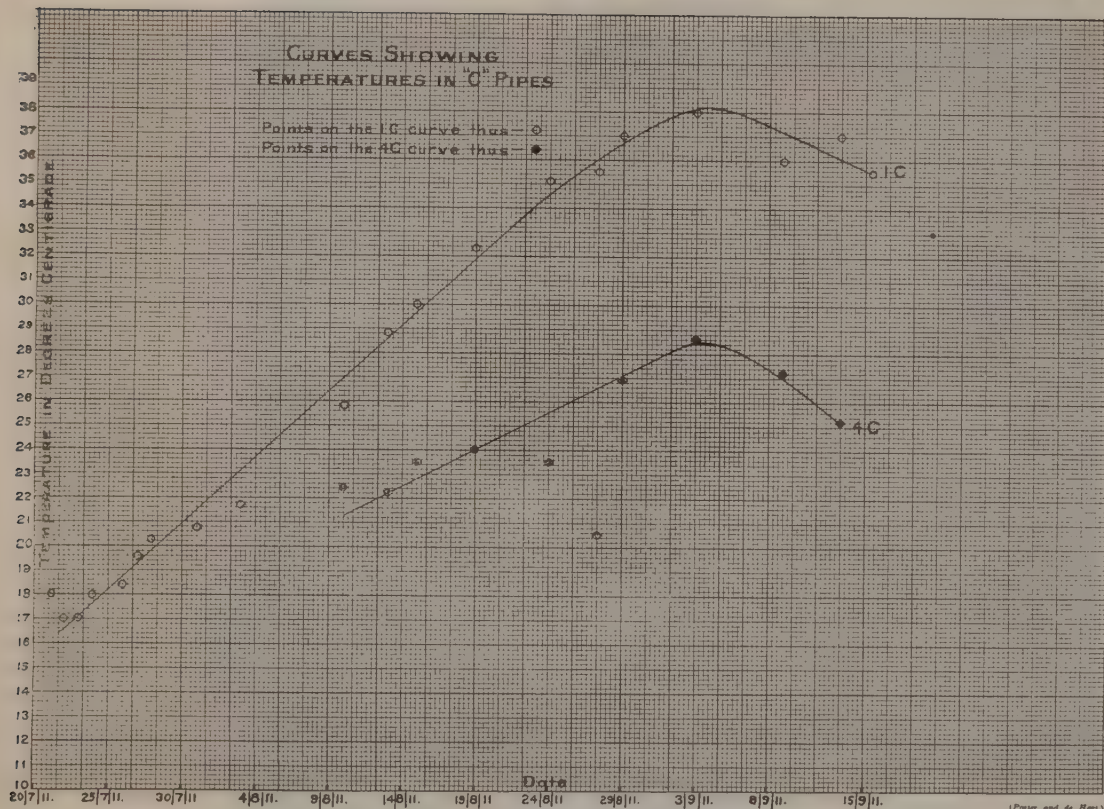


FIG. 61. Graphic record of temperature in C pipes, Glace Bay, N.S.

(Parker and de Hart.)

mentioned above. About 250 cubic centimetres were first drawn off and discarded in order to ensure the removal of all air from the tube. Then 250 c.c. of gas were taken. The standard methods of analysis with absorption pipettes were employed. Practically no carbon dioxide or heavy hydrocarbons were found in the gases evolved, but even in the case of the stock coal the oxygen content was always low. It has been noted that the oxygen content is very variable, but there seems to be no connexion between its variations and the pressure, temperature or relative humidity readings, these consequently are omitted from Table XLVII.

TABLE XLVII.

## Oxygen in Gas Samples from Glace Bay Storage Piles.

*(Porter and de Hart)*

OXYGEN IN PER CENT.

Date.	Pile 1.	Pile 2.	Pile 3.	Pile 4.
Aug. 13.....	19.8	20.8	20.6	20.6
Aug. 16.....	19.2	20.0	20.4	18.9
Aug. 20.....	20.3	20.6	20.6	20.5
Aug. 24.....	20.7	20.4	20.4	....
Aug. 27.....	20.1	20.6	20.4	20.2
Aug. 29.....	20.1	20.2	20.4	20.8
Aug. 31.....	19.9	20.2	20.4	19.9
Sept. 3.....	20.4	20.3	20.2	20.1
Sept. 7.....	20.3	20.3	20.3	20.2
	20.1	20.4	20.4	20.2
Sept. 8.....	20.1	20.4	20.4	20.3
	20.2	20.3	20.4	20.3
Sept. 10.....	20.2	20.4	20.4	20.3
	20.2	20.3	20.3	20.3
Sept. 11.....	20.4	20.4	20.4	20.6
	20.5	20.3	20.6	20.4

After September 3, duplicate sample tubes were filled with gas, one immediately after the other in order to check the analysis. The results of both analyses are given.

These figures show a slight depletion of oxygen. Although the samples from pile 1, which became hotter than any of the other piles, shows the lowest oxygen content, the oxygen of the samples does not appear to diminish as time goes on, and oxygen from the air must therefore have obtained access to the interior of the pile.

Attempts were made to determine the relation of the gas-pressure in the heart of the pile to the atmospheric-pressure outside by means of the small pipes already referred to. The apparatus used was that which had been employed by Porter and Brunton at Angus, see page 159. It was found almost impossible to get satisfactory readings except in very quiet weather, as the small, but frequent changes in the external pressure due to the wind masked the still smaller differences in pressure in the piles. Owing to this difficulty the number of reliable readings obtained is far too small to prove anything, they are, however, given here as an indication of the amount

of pressure or suction, and in the hope of stimulating further experimental work along this line.

TABLE XLVIII.  
Pressures in Interior of Glace Bay Storage Piles.  
(Porter and de Hart)

Date	Pressure in inches of water.			
	Pipes			
	1B	2B	3B	4B
Aug. 11.....	-0.0066	-0.0091	-0.0054	-0.0048
Aug. 16.....	+0.0195	+0.0113	+0.0136	+0.0082
Aug. 20.....	-0.0174	-0.0206	-0.0162	-0.0000
Aug. 24.....	-0.0223	-0.0131	-0.0022	-0.0264
Aug. 27.....	+0.0438	+0.0024	-0.0000	-0.0000
Aug. 29.....	+0.0012	-0.0000	-0.0000	-0.0000

+ signifies pressure, — signifies suction.

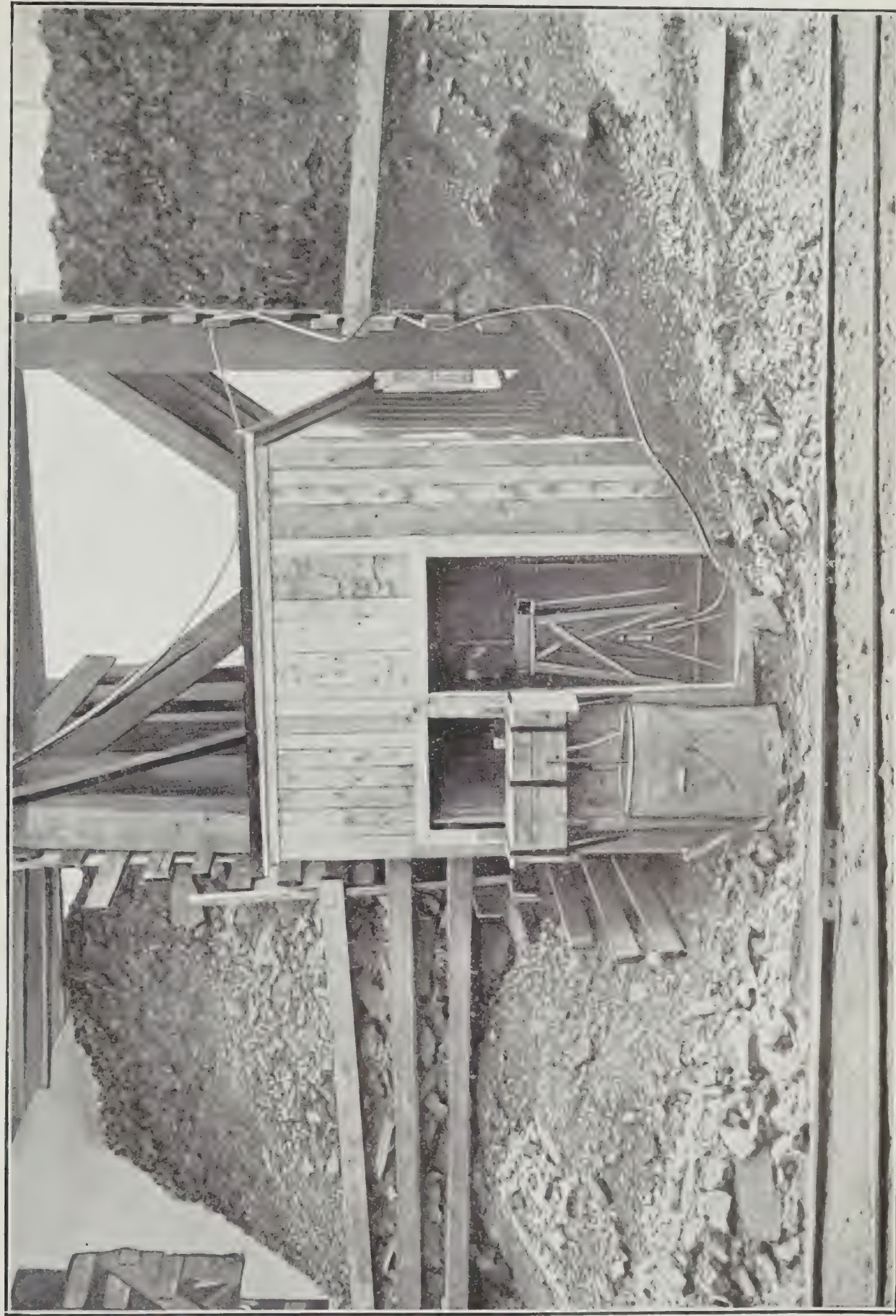
August 21 being a very still day it was found possible to take readings with one limb of the U tube open to the air, and in all four cases these readings checked exactly.

It will be noted that there is no case in which some of the piles showed pressure and others showed suction. Hence it is natural to look to external causes for the changes in pressure. A study of the barometric and thermometric readings and of the relative humidity shows that there may be some relation between the atmospheric conditions and the pressure changes in the pile, but, owing to the very small number of readings obtained and their small amount, it is unwise to attempt to draw any conclusions of weight from the records.

No barometer readings were taken on August 11, as the barograph was not available on that date. With the exception of the reading 1B on August 27, however, the records show no suction when the barometer was falling and no pressure when it was rising.

At the conclusion of the Glace Bay experiments above outlined, Mr. de Hart observed the loading of a collier belonging to the Dominion Coal Company, one hatch of which was loaded with freshly mined coal from a single one of the Company's mines, while the remainder of the cargo was made up of ordinary mixed coal as it came to the loading pier.

Mr. de Hart then went to Montreal on the collier and observed the unloading, and saw that all of the coal from the particular hatch under observation was shipped to the Canadian Pacific Railway's storage yard at Outremont, Montreal, where in turn he saw it piled according to the standard Canadian Pacific Railway method, detailed on page 152. He then put observation tubes in the pile and connected them up with the apparatus which had been used by Porter and Brunton a year before,



(Porter and de Hart)

Detailed view of pile observation station at Glace Bay.



and commenced a series of observations similar to theirs. Owing, however, to the fact that the coal was piled in comparatively cool weather no very great amount of heating took place. The observations, however, confirm in every respect the results previously obtained by Porter and Brunton as set forth in the following pages.

*Porter and Brunton Experiments at Angus.*

In the winter of 1910-11, J. B. Porter and J. S. L. Brunton carried out an extended series of observations on a very large storage pile, which had been built by the Canadian Pacific Railway between June and October, 1910, at Angus, Montreal, in accordance with their standard method, which has already been described on page 152. This investigation, although made before the Sydney experiments already outlined, is described after them for obvious reasons. The pile which was roughly triangular in shape was approximately two hundred yards long, eighty-five yards wide, and fifteen feet high; it contained approximately fifty-eight thousand tons. The underlying ground was the natural soil of the location—a firm sandy clay—levelled off and covered with a layer of about 1 ft. of roundhouse cinders.

The purpose of the investigation was (1) to study the temperature changes, and (2) to investigate the “breathing” of the pile, that is to say, to determine where and how air entered and escaped and whether barometric changes had any important effect upon ventilation.

A rectangular plot, 80 ft. by 90 ft. was laid out, one end of which was the northern edge of the pile. In one half of this experimental area all of the ventilation holes were filled up with fine coal, thus forming an unventilated block 90 ft. by 40 ft. An instrument house and six observation stations were located in the plot, three stations being in the unventilated area and three in the ventilated portion, as shown in Fig. 62, and in Plates I, II, and VI. Each station comprised a group of three one-inch pipes of varying lengths, each pointed and drilled with some  $\frac{1}{4}$ " holes near the bottom to permit the entrance or escape of gas, and closed at the upper end with a threaded cap with a hose connexion. In each group pipe No. 1 was driven 9 ft. down into the coal, No. 2, 14 ft., and No. 3, 16 ft., i.e., just into the cinders below the pile. A small building to house the instruments was erected upon the pile in the position M as shown in the sketch. The instruments themselves were as follows:—

1. A standard thermometer, graduated in degrees Centigrade.
2. 2 doz. maximum recording thermometers, graduated from 0°—300°C. for measuring the temperature in the pipes.
3. A Richard thermograph reading to one degree Fahrenheit. This instrument was checked against a standard thermometer and was found very reliable. It and the thermometer were kept in a small latticed box fixed to the outside of the house on the northern side.

4. Two barographs, one being kept in the house and the other being in a constant temperature room at McGill University about a mile and one-half distant.
5. A Shaw-Dines microbarograph which was kept in the constant temperature room at the University.
6. A kathetometer, fitted with a micrometer eyepiece, capable of reading  $1/100$ th of 1 millimetre.
7. A standard anemometer for noting wind velocities.
8. A delicate pressure gauge in the form of a U tube with the necessary connexions and stopcocks for adjustment. Toluol was the liquid employed as it combined extreme lightness with low viscosity even at very low temperatures. This gauge was suspended on the wall of the house.
9. Rubber hose 200 ft. long and iron gas pipe connexions for attaching the pipes to the pressure gauge.

The temperatures were obtained easily and accurately by lowering the recording thermometers inside the pipes to the required distance and allowing them to remain in position for some minutes, after which they were withdrawn and the temperatures read.

To obtain trustworthy pressure readings was a much more difficult matter. The method adopted was to remove the cap from the top of the pipe to be tested and in its place screw on a coupling which connected by means of very heavy rubber hose with a system of piping leading to one leg of the pressure gauge.

In the preliminary tests the other leg was left open, but it was found that under these circumstances the gauge sometimes showed pressures in the pipe, and at other times slight vacua, and whenever there was any wind the liquid surged more or less constantly, the fluctuation sometimes amounting to 10 or 15 millimetres. Various experiments were next made to eliminate the effect of the wind on the open leg of the gauge. Fairly satisfactory results were got by connecting this leg with a pipe which terminated in a barrel of crushed coal equally exposed on all sides to the wind, but finally it was discovered that pipes 2 and 3 at Station A made even more satisfactory dampers. These pipes were close to the edge of the pile and an exhaustive series of tests under all sorts of weather conditions failed to show any sign either of pressure or vacuum in them. At the same time the bottoms of the pipes were deep enough in the coal to be perfectly protected from gusts of wind. In all of the later and more trustworthy determinations of pressure, the "open" end of the U gauge was connected with one of these two pipes, and the other end was connected with whatever pipe was at the moment under observation.

Each leg of the gauge had a by-pass to the air controlled by well ground glass stopcocks. After the connexion had been made these stopcocks were both opened and the toluol permitted to come to a level. The kathetometer was then sighted first on one leg and then on the other and adjusted

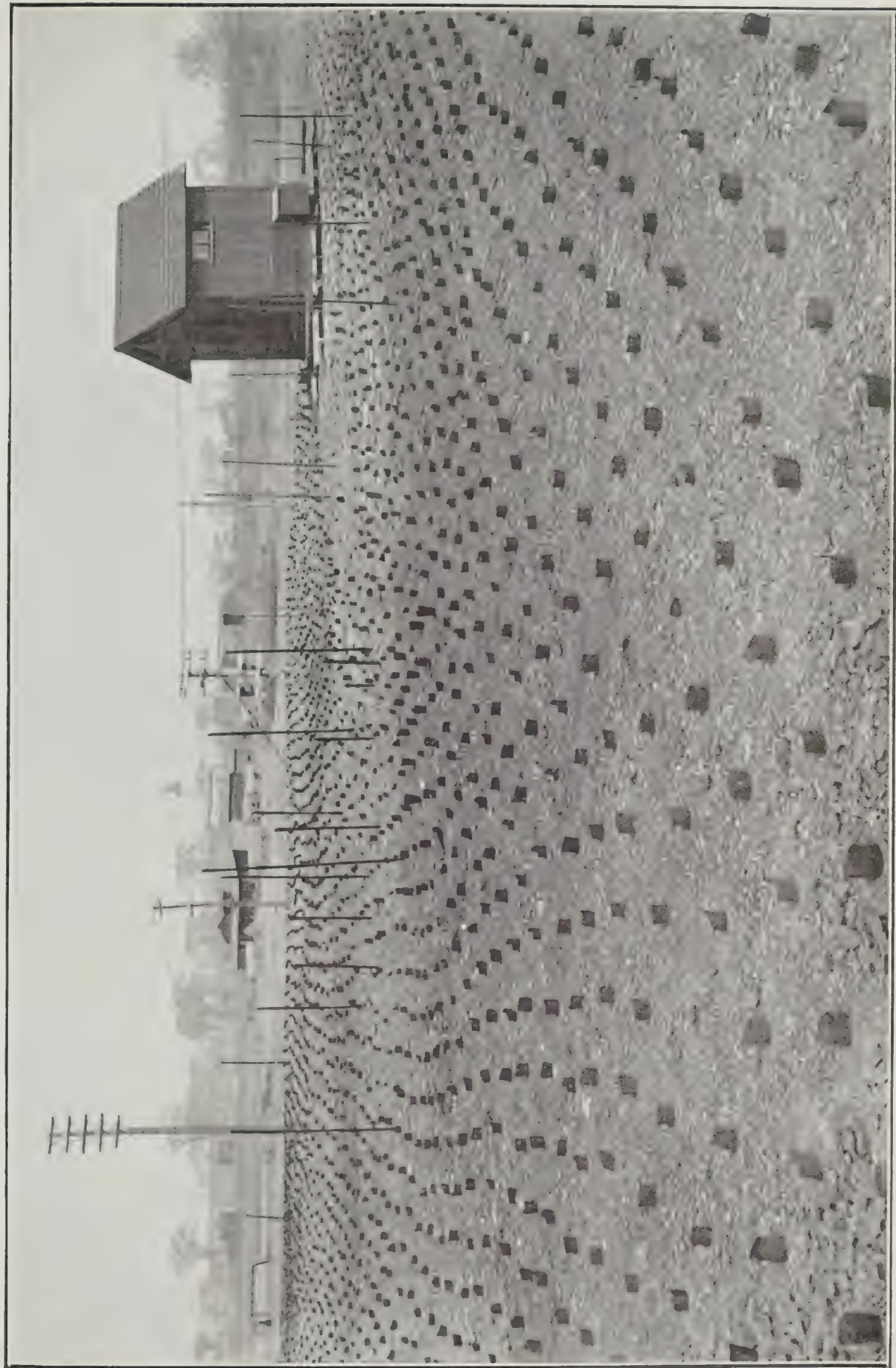
TABLE XLIX.  
General Observations at Angus Storage Pile.  
(Porter and Brunton)

Date.	Jan. 10.	Jan. 12.	Jan. 16.	Jan. 19.	Jan. 23.	Jan. 26.	Jan. 30.	Feb. 6.	Feb. 9.	Feb. 13.	Feb. 15.	Feb. 20.	Feb. 27.	Mar. 6.	Mar. 9.	Mar. 15.	Mar. 23.	Mar. 27.	April 6.	April 10
Temperature .....	-7	-16	-19	-4	-5	-11	-15	-20	-1	-11	-18	-11	-11	-8	+2	+1	-5	+9	.....	.....
Rising +, Falling -	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average for 24 hours .....	.....	-15	.....	.....	-10	-12	.....	.....	-5	-15	.....	-13	.....	-11	-1	-1	-7	.....	+4	+2
Barometer .....	29.58	30.15	.....	29.15	30.10	29.90	29.05	30.17	29.70	30.10	29.60	29.60	30.15	29.80	29.20	29.70	29.35	.....	.....	.....
Rising +, Falling -	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average for 24 hours .....	.....	30.44	.....	.....	30.45	30.35	.....	.....	30.05	30.25	.....	30.01	.....	30.44	30.07	29.57	29.90	.....	29.61	30.43
Wind .....	N.	.....	.....	.....	S.W.	N.	N.W.	.....	S.W.	N.	.....	N.W.	.....	N.	S.E.	S.W.	W.	.....	S.W.	W.
Velocity m. p. h. ....	10	.....	.....	.....	11	14	35	.....	4	12	.....	9	.....	11	10	17	23	.....	20	14
Station A. Pipe 1 Temp. ....	4	5	.....	.....	5	5	.....	5	.....	5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
" 2 " .....	2	0	.....	.....	0	0	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
" 3 " .....	0	.....	.....	.....	0	0	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Station B. Pipe 1 Temp. Press. ....	13	13	14	14	15	.....	16	16	0	12	.....	19	19	15	14	3	13	13	13	10
Pipe 2 Temp. Press. ....	6	8	7	7	7	.....	7	7	0	14	.....	.....	.....	9	.....	5	.....	.....	.....	.....
Pipe 3 Temp. Press. ....	7	7	7	6	7	.....	5	6	7	.....	.....	.....	.....	9	.....	7	.....	.....	.....	.....
Station C. Pipe 1 Temp. Press. ....	35	36	37	39	38	.....	39	39	37	36	30	0	.....	16	10	9	10	6	0	.....
Pipe 2 Temp. Press. ....	17	18	19	17	17	.....	16	17	28	.....	7	.....	.....	18	15	.....	.....	.....	.....	.....
Pipe 3 Temp. Press. ....	15	18	23	27	25	.....	22	18	26	.....	13	.....	.....	10	.....	.....	.....	.....	.....	.....
Pipe 4 Temp. Press. ....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6
Pipe 5 Temp. Press. ....	.....	.....	.....	.....	.....	.....	.....	.....	.....	35	.....	7	.....	0	0	8	10	.....	11	17
Pipe 6 Temp. Press. ....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Station D. Pipe 1 Temp. Press. ....	2	2	.....	2	2	15	.....	2	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pipe 2 Temp. Press. ....	0	0	.....	0	0	.....	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pipe 3 Temp. Press. ....	0	0	.....	0	0	.....	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Station E. Pipe 1 Temp. Press. ....	10	11	11	11	12	0	.....	12	13	0	.....	14	.....	.....	.....	4	16	17	.....	.....
Pipe 2 Temp. Press. ....	5	5	6	5	5	.....	6	6	.....	.....	0	.....	.....	7	10	14	12	.....	.....	.....
Pipe 3 Temp. Press. ....	5	4	5	5	5	.....	6	6	.....	.....	.....	.....	.....	0	15	15	.....	.....	.....	.....
Station F. Pipe 1 Temp. Press. ....	17	13	15	15	16	.....	18	18	0	.....	18	.....	.....	.....	.....	19	.....	11	21	.....
Pipe 2 Temp. Press. ....	12	13	14	14	14	.....	13	14	.....	19	.....	.....	.....	.....	.....	.....	.....	.....	.....	6
Pipe 3 Temp. Press. ....	15	14	13	13	14	.....	13	13	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

\* For temperatures of the C. group of pipes, Feb. 10—March 16. See Table LI.  
† Two of these determinations are less trustworthy than the others.

Note.—Barometer readings in inches. Thermometer in Centigrade degrees. Pressures in 1.100 millimetres of water gauge approximately.





Experimental area at Angus.

(Porter and Brunton)



to a zero reading; both stopcocks were then closed and the difference in height of the two legs read. It was discovered, rather to the surprise of the observers, that the change in level reached its maximum in a few moments and thereafter the pressure did not increase, and that in no case did this pressure amount to more than a millimetre or two of toluol, equivalent to less than 1 millimetre of water. It was also noted that while the pipes frequently showed no differences of pressure from the outside air, yet when there was any difference the pressure in the pipe was always greater than that of the atmosphere although the difference as stated above was minute.

Table XLIX gives a long series of observations of temperatures and barometric pressures both at the surface and in the pipes. It records all observations of pipe pressures which were considered at all trustworthy. In general this pressure was highest in the portions of the pile which heated, but in no case did it exceed a minute amount and the only conclusion which can safely be drawn from these observations is that the interior of the pile could not at any time, even on a rising barometer, have drawn in any appreciable amount of air through its top surface.

In this connexion careful experiments were made to see whether any air was sucked in through the ventilation holes, but the most delicate apparatus which could be devised failed to show an entering current in any case, whereas in a number of cases a slight outward current was observed.

It should be noted that in extremely cold and quiet weather the ventilation holes over the whole surface of the pile were always observed to be giving off small amounts of vapour, which often showed as little columns of steam. Much of this exhalation was no doubt aqueous vapour from the moisture contained in the coal and from melted snow, but undoubtedly some air was also exhaled, and it must therefore be assumed that fresh air entered the pile, chiefly no doubt by diffusion but also, probably, around the sides.

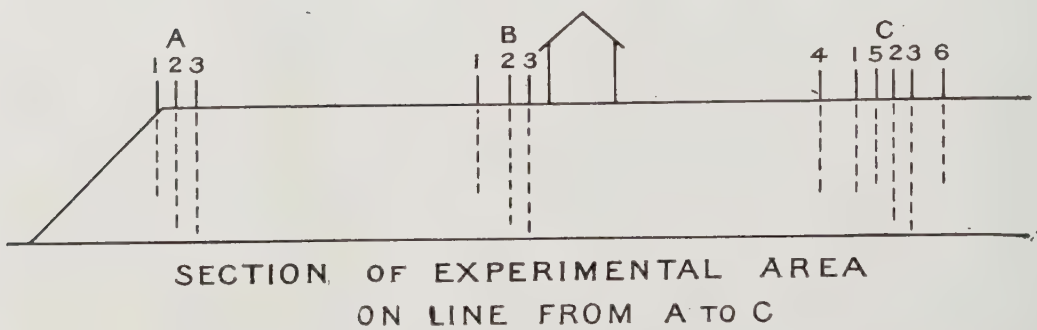
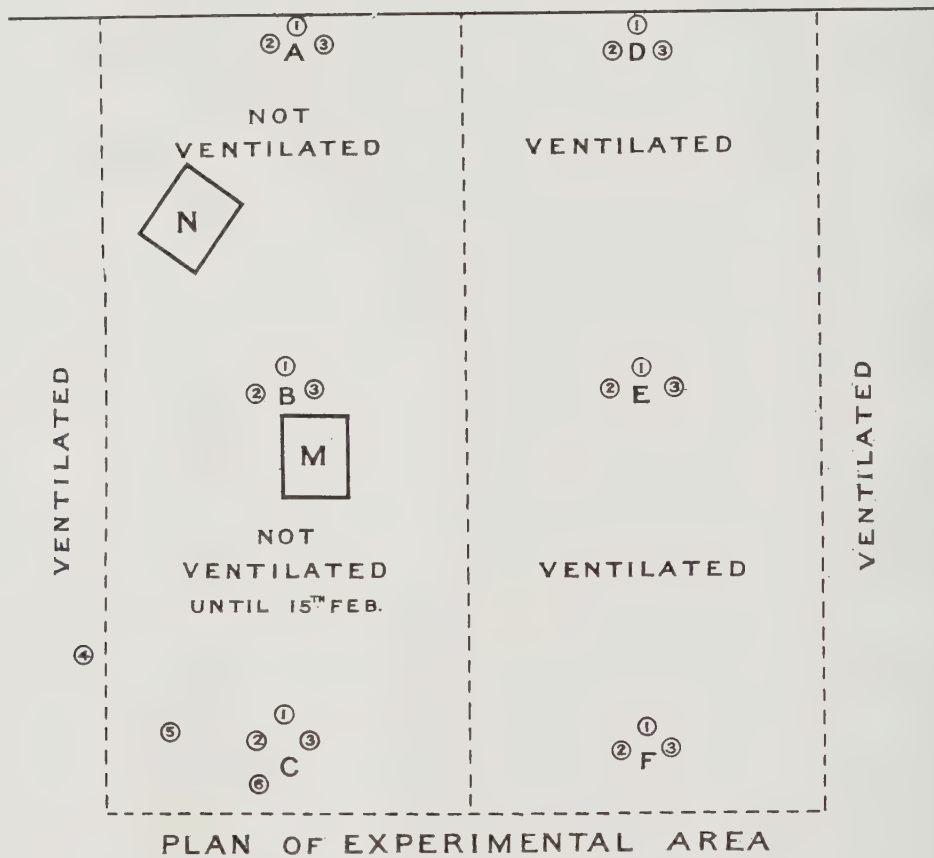
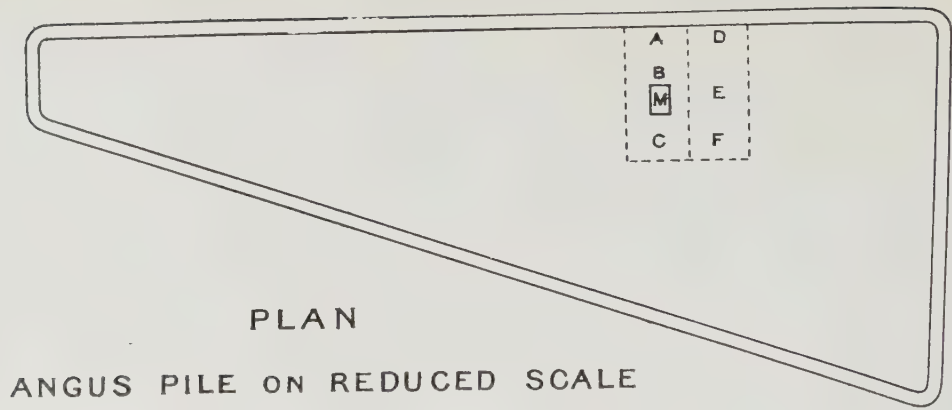
Samples of the atmosphere or gas contained in the pile were drawn on February 13 from three pipes which showed unusually high temperatures and pressures. These samples were analysed by Mr. Edgar Stansfield, M.Sc., Chief Chemist of the Fuel Testing Division of the Mines Branch, Department of Mines, Ottawa, and the results are shown in Table L.

TABLE L.  
Analyses of Gas Samples from Angus Storage Pile.

(Porter and Brunton)

Pipe.	Depth.	Temperature.	Pressure. <sup>1</sup>	CO <sub>2</sub>	O <sub>2</sub>
				%	%
C 5	7	—	35	0.5	16.8
C 6	14	—	—	0.3	18.8
F 2.....	14	13	19	0.1	20.0

<sup>1</sup> Pressures in  $\frac{1}{100}$  millimetres of water.



(Porter and Brunton.)

FIG. 62. Plans and elevation of Angus pile, Montreal.

Table XLIX, p. 160, records not only the temperature observations at the bottom of the pipes, but also the surface temperature at the central station, observed at the same time. It will be noted that groups A and D did not heat appreciably. This might have been expected as they were very close to the edge of the pile and the external temperature was almost constantly below zero. On the other hand the inner groups and particularly group C in the unventilated portion heated very decidedly. The temperatures shown in the table are only those observed at the bottom of the pipes, and considerably higher records were observed at depths of from six to eight feet in spite of the fact that the pile was at this time covered with a foot or two of snow.

Early in February a number of iron observation rods were driven into the unventilated portion of the pile particularly in the neighbourhood of group C, and on February 10 some of these were found to be hotter than any of the group C pipes; therefore additional pipes were driven to a depth of about ten feet at these points and daily observations were made until February 15 when the owners of the pile concluded that the heating was approaching the danger point, and the pile must be ventilated. On that day, therefore, the observation hut was moved from its original position M, to N, Fig. 62, and the whole of the heated portion of the pile was opened up by the usual method of driving two inch bars to the bottom and withdrawing them as explained on page 153.

TABLE LI.

**Detailed Observations of Heating in Angus Pile.***(Porter and Brunton)*

Date		Feb. 10	12	13	14	15	16	20	27	Mar. 6	9	16
Pipe C1	6 ft.....	.....	.....	.....	44	44	42	33	.....	.....	16	.....
"	7 ft.....	42	43	.....	.....	.....	.....	.....	.....	.....	.....	.....
"	8 ft.....	38	37	.....	.....	36	.....	30	25	18	.....	.....
Pipe C2	6 ft.....	.....	43	.....	.....	.....	.....	.....	.....	.....	.....	18
"	10 ft.....	.....	38	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pipe C4	6 ft.....	.....	24	29	34	34	33	29	20	18	19	.....
"	8 ft.....	.....	25	.....	.....	26	31	28	.....	.....	.....	.....
"	10 ft.....	.....	19	.....	.....	14	.....	.....	.....	.....	.....	.....
Pipe C5	6 ft.....	.....	56	56	55	55	50	41	.....	.....	.....	.....
"	8 ft.....	.....	47	.....	.....	55	48	39	30	23	22	19
"	10 ft.....	.....	.....	.....	.....	55?	.....	.....	.....	.....	.....	.....
Pipe C6	6 ft.....	.....	50	48	.....	45	49	42	31	26	19	.....
"	8 ft.....	.....	.....	.....	.....	45	43	42	.....	.....	.....	.....
"	9 ft.....	.....	46	.....	.....	.....	.....	.....	.....	.....	.....	.....
"	10 ft.....	.....	.....	.....	.....	17	.....	.....	.....	.....	.....	.....

NOTE.—This portion of the pile was unventilated from December 10 until February 15, by which time it had heated to such an extent that it was considered necessary to ventilate it in order to avoid fire. The ventilation holes were driven in the usual way on February 15, and the pile immediately began to cool off.

Table LI, p. 163, which gives a detailed record of the temperature at different depths in the group C pipes, shows that the result of this ventilation was an immediate and comparatively rapid cooling of the coal.

From a scientific point of view it is to be regretted that the heating could not have been permitted to proceed further, if possible even to actual ignition, but the action of the owners of the coal was of course perfectly reasonable, particularly as the heating was in a part of the pile which would have been very expensive to dig out or flood.

It is interesting to note that the above series of observations prove very clearly that the maximum heating was comparatively near the surface of the pile. As a matter of fact the hottest points were apparently not more than five or six feet from the surface, although the weather at the time was extremely severe. The common opinion of practical men in charge of coal storage is that fires usually occur close to the bottom, but in this case it is almost certain that had the pile been left unventilated it would have ignited within a week or two at a depth of not over six feet, and in certain other cases which the author has observed, fires in large piles have actually originated at this depth. The probable reason is that in a pile of great extent and depth, the coal in the lower portions is so heavily compressed and so isolated from supplies of fresh air that it does not receive sufficient oxygen. It must be confessed, however, that the persons responsible for coal storage are not willing to act upon this theory, which, if followed to a logical conclusion, would lead to the storage of coal in very deep piles on ground impermeable to air.

### **General Conclusions and Recommendations.**

It is clear from what has been said in the preceding pages that there is an enormous difference in the liability of coals to weather. This explains the fact that in spite of the very large amount of experimental work which has been done on the subject, authorities still differ considerably as to the causes and prevention of deterioration. Almost every piece of experimental work which has been done has been upon specific coals, usually from a single district, and the conclusions arrived at have naturally referred primarily to these coals and only in a lesser way to coals in general. It is therefore still impossible to formulate any comprehensive rules for the prevention of weathering, but nevertheless it is desirable to attempt to close this section of the report with a summary statement of the opinions of the most competent authorities.

The subject may be considered under two heads: first, mere deterioration or loss of calorific value; second, spontaneous combustion resulting in the actual destruction of the coal.

As to deterioration due to exposure irrespective of fire, it is a very serious matter with lignite, as has already been pointed out on pages 26, and 151, and lignites and lignitic coals cannot be stored more than a few weeks or months at the most without becoming almost valueless. Bituminous coals suffer less, but gas coals deteriorate sufficiently in respect of their gas producing qualities to make the question of long storage a serious

one in many cases. Exposure also rapidly decreases the coking qualities of many coals; this subject is considered again on page 172 and is discussed at length in the author's "Coals of Canada," but it is not a matter of very great commercial importance as it is rarely if ever desirable to store coal for any length of time before coking.

All coals but anthracite thus lose some of their calorific value on weathering, but with the exception of lignite and the lignitic coals above referred to, this loss rarely amounts to more than a few per cent of the total theoretical value, and fortunately the actual loss in service is usually even less, as the most easily weathered constituents are generally speaking those which are largely lost as smoke in ordinary use.

The most serious commercial damage which coal suffers in storage is due to the disintegration which results chiefly from the extra handling involved, but also in part from weathering proper, and in part from the crushing due to the weight of the superincumbent coal in storage piles. The total loss from these causes is usually very considerable, and as different coals differ greatly in strength, it is very well worth while for persons who have to store fuel, to experiment with the several coals available with a view to securing the one least liable to break up into slack.

In the matter of actual prevention of fires it may be concluded that all coals except the true anthracites are liable to spontaneous combustion under very unfavourable conditions, but with the exception of the lignites and lignitic coals, storage of most coals is practicable in a commercial sense in temperate countries provided reasonable precautions be taken. These precautions may be briefly stated in order as follows:—

1. Any coal can be safely stored under water, and if silt, etc., be excluded little or no deterioration takes place. This method of storage is very costly, and it is, therefore, not practicable except as a last resort.

2. Lump or screened coal except of the lignitic varieties can usually be stored with little or no danger. The size of the lumps is not ordinarily a matter of great importance so long as the screening devices ensure the complete removal of slack and dust. It must be noted, however, that unless lump coal is piled carefully and to small height a sufficient amount of crushing takes place to produce dust in the bottom of the pile. Owing to the cost of screening and the difficulty of disposing of the resultant slack this method is not generally practicable, and the following notes apply to where it is necessary to store run-of-mine coal or its practical equivalent in respect of fines due to secondary crushing, caused by rehandling.

3. Coal stored in cold weather is much less likely to give trouble than that which is stored in summer, and in cases where summer storage is necessary, risk of heating is much less if the pile is built during cloudy or cool weather. In very hot climates, or with very susceptible coal, covered storage may be justified as a means of protecting the coal from the sun not only during piling, but afterwards, although the later exposure is less serious.

4. Shallow piles are much less likely to give trouble than deep ones owing to their ample ventilation and the readiness with which they give

off any excess of heat. The critical depth depends upon the coal and the conditions at the time of its storage; some coals will fire if piled even 4 feet deep, but ordinarily from 8-10 feet is safe and many coals may be stored to much greater depth.

5. Some coals, particularly those high in sulphur, undoubtedly heat more readily if damp, and in such cases exposure to rain and particularly to alternate wetting and drying is probably harmful. In some cases covered sheds are considered justifiable on this ground. In other cases piles have been protected by covering them with a layer of slack or coal dust.

In connexion with this question of rain it should be noted that the New South Wales Commission advocates wetting the coal thoroughly at the time of storage, the reference being particularly to ships' cargoes, and while this is contrary to ordinary practice it is extremely probable that many coals would stand more safely if treated in this way.

6. Ventilation either by the means described on page 152, or by the insertion of numerous perforated pipes is no doubt the most practical method of preventing fires, and by its use storage piles can be made larger and higher than otherwise. This method has been so fully discussed that it need not be further dealt with here.

7. Chemical treatment has proved successful in some cases. The material used is commonly either a solution of calcium chloride or of some other cheap hygroscopic salt. Several experimenters and commercial concerns state that they have found it effective to sprinkle the coal pile freely with a 10 per cent solution of calcium chloride. The cost of this treatment is possibly less than that of ventilation by the method referred to, but whether it is equally effective remains to be determined for each particular case.

8. Whatever method is used, and particularly in cases where no method of prevention is employed, a storage pile should be watched carefully, particularly for the first few weeks after it is built. Probably the simplest way of doing this is to have a large number of sharp pointed iron rods about one inch in diameter driven into different parts of the pile and left for a few hours, and then to shift them to other parts. An experienced man can very easily judge by handling the rods whether there is any undue heating, and a comparatively small amount of labour suffices for the observation of a large storage pile. If heating is observed it can be watched by driving pipes into the heated spots and using thermometers as already described. If the heating increases to a point approaching that of "auto-genous oxidation" the pile should be ventilated or if necessary dug out or flooded. Among practical men there is a very strong prejudice against flooding, but probably this is not often justified. In place of flooding the use of sulphur dioxide gas or carbonic acid gas has been advocated. These gases are purchasable under high compression, and can be forced into the body of the pile by means of pipes driven down into the heated portion. Coal mine fires have been extinguished by this means, and it has also been used on board ship, and it undoubtedly would be effective in ordinary storage if the gas were used freely.

## CHAPTER VII.

THE EFFECT OF SLOW WEATHERING ON THE COMPOSITION  
AND CALORIFIC VALUE OF COAL, WITH ESPECIAL  
REFERENCE TO CERTAIN CANADIAN  
CRETACEOUS COALS.

Under ordinary present day conditions very little time is lost between the mine and the furnace. Circumstances which have already been discussed of course necessitate the storage of reserve supplies, etc., and the aggregate amount of such supplies is very great, but a far greater part of the world's coal is now mined by quick recovery methods and once mined it is hurried to the consumer to be burned and "turned into power." Even the stored coal is rarely kept more than a few months or at the utmost a year, and on the whole, therefore, coal has not time to weather to any great extent, and if we omit the lignites we may say that in a commercial sense coal does not suffer much loss from such weathering as it ordinarily gets, and that our great concern with the matter is due to the risk of fire and total destruction rather than to mere calorific deterioration, etc.

The problem of slow weathering is, however, of considerable scientific interest, and is also of some practical importance as a means of enabling us to predicate the character of the deeper parts of a coal seam from the samples of weathered coal discovered at the outcrop.

In 1865 **Fleck**<sup>1</sup> investigated the nature of the changes which occur when coal is weathered. In 1856 a large quantity of each of six kinds of Saxon coal had been sampled and analysed. The remainder of the samples in lumps were kept until 1865 in a case at the Polytechnic Institute in Dresden, where they were again sampled and analysed by Fleck. The results of these analyses are shown in table LII.

It will be seen that the percentage of ash is very much larger in the samples which had been stored for nine years. The matter constituting the ash could not have increased by oxidation to any such extent, (in some cases about 18 per cent), it must therefore be inferred that the samples analysed in 1865 did not contain the same proportion of inorganic matter respectively as those analysed in 1856, and while weathering undoubtedly caused part of this change, bad sampling must be responsible for the rest. It is therefore impossible to draw any trustworthy conclusions from the analyses as they stand. There is very good reason to believe, however, that while inorganic matter is frequently unequally distributed through a seam of coal, the organic matter in that seam is much less subject to variation in chemical composition. If this be so, conclusions may safely be drawn from Fleck's figures recalculated to show the percentage composition exclusive of ash, that is carbon, hydrogen, oxygen and nitrogen,

<sup>1</sup> Die Steinkohlen Deutschlands, etc. Vol., 2, 1865, p. 221. Quoted Percy Metallurgy-Fuels, 1875, pp. 290-2.

TABLE LII.  
**Analyses of Fresh and Stored Coal.**  
*(Recalculated from Fleck)*

Kinds of coal.	Year in which the analysis was made.	Percentage composition of the coal. Dried at 105°C.				Percentage composition exclusive of ash.			Hydrogen per 1000 parts of carbon.	
		Carbon.	Hydrogen.	Oxygen and nitrogen.	Ash.	Carbon.	Hydrogen.	Oxygen and nitrogen.	Disposable.	Non-disposable.
All from Carboniferous System.										
1 Hard shaly coal from the Oppelt pit in Zaukeroda.....	1856	67.173	4.630	11.456	16.739	80.768	5.567	12.965	48.856	20.069
	1865	47.219	2.814	14.979	34.988	72.632	4.398	22.970	21.024	39.528
2 Soft coal from the third seam of the Oppelt pit.....	1856	26.544	1.904	7.320	64.232	74.230	5.325	20.445	37.303	34.434
	1865	32.779	1.756	11.132	53.333	70.241	3.764	25.995	7.331	46.255
3 Coal from the second seam of a colliery (des Gühneschen Werkes) in Niederwürschnitz.	1856	81.573	4.477	9.473	4.477	85.396	4.687	9.917	40.365	14.520
	1865	80.300	4.650	13.569	1.481	81.510	4.720	13.770	36.793	21.114
4 Soft shaly coal from the Gückelsberg pit.....	1856	87.825	2.663	4.670	4.842	92.295	2.798	4.907	23.669	6.646
	1865	86.217	2.653	5.160	5.970	91.434	2.822	5.744	23.010	7.853
5 Coal (Pechkohle) from Helbigs & Co.'s pit in Oberhohndorf.....	1856	80.963	5.518	12.081	1.498	82.113	5.602	12.285	49.518	18.705
	1865	73.472	4.645	19.728	2.155	75.972	4.747	19.281	30.761	31.722
6 Coal from the upper seam of the Segen Gottes pit in Zwickau.	1856	75.747	4.881	15.570	3.802	78.740	5.074	16.186	38.748	25.692
	1865	76.363	4.166	16.555	2.916	78.658	4.272	17.070	27.168	27.131

disposable hydrogen and non-disposable hydrogen. This has been done and the figures show that in every instance the proportion of disposable hydrogen had decreased, while the proportion of the non-disposable hydrogen had increased relative to the amount of carbon. His analyses do not give the amount of oxygen in the samples, but it is clear that weathering must have increased the percentage of this element very materially, the coals must, therefore, have suffered a considerable loss of calorific value during the nine years which elapsed between the two series of analyses.

**Parr and Wheeler** whose work on the oxidation of coal in storage has been described at considerable length on page 69 et seq., secured samples of old outcrop coal, pillar coal, and storage piles of unusual age, and determined the loss in calorific power. Their results are set forth in Tables LIII and LIV.

TABLE LIII.

## Analyses of Pillar Coal and Outcrop Coal compared with Fresh Coal.

*(Parr and Wheeler)*

Description.	Total. mois- ture.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease.	
		Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.
ST. CLAIR COUNTY, ILLINOIS.							
Fresh coal.....	9.76	15.80	4.76	12,202	14,896	—	—
Pillar coal. (Exposed 22 years)...	10.18	16.21	5.01	11,797	14,482	414	2.78
GALLATIN COUNTY, ILLINOIS.							
Fresh coal.....	4.47	10.85	3.72	13,235	15,133	—	—
Pillar coal.... (Exposed 27 years.)	4.76	12.84	3.84	12,514	14,857	276	1.82
PEORIA COUNTY, ILLINOIS.							
Fresh coal.....	13.86	16.25	3.91	12,044	14,757	—	—
Outcrop slightly cover- ed with soil.....	29.81	16.86	0.85	9,257	11,331	3,426	23.21

TABLE LIV.  
Analyses of Fresh and Stored Coal.  
(Parr and Wheeler)

*Commonwealth Edison Company, Chicago.*

Sample taken.	Dry coal.			B.Th.U. referred to actual or unit coal.	Decrease	
	Ash.	Sulphur.	B.Th.U.		B.Th.U.	Per cent.
FRANKLIN COUNTY, ILLINOIS.						
<i>Nut Coal.</i>						
April, 1908.....	10.16	1.81	13,021	14,688	—	—
July 14, 1909.....	10.44	2.15	12,924	14,642	46	0.31

WILLIAMSON COUNTY AND FRANKLIN COUNTY, ILLINOIS.  
*Egg Coal.*

April, 1908.....	10.97	2.35	12,909	14,728	—	—
July 14, 1909.....	11.49	1.84	12,697	14,559	169	1.15

WILLIAMSON COUNTY, ILLINOIS.  
*No. 1 Washed Nut.*

April, 1908.....	9.21	1.82	13,205	14,726	—	—
July 14, 1909.....	9.43	1.72	13,008	14,540	186	1.26

A number of experiments were made to determine the loss of calorific value of certain Illinois coals due to weathering. A table of analyses compiled from curves shown in a paper by **Parr and Hamilton**<sup>1</sup> is given below.

TABLE LV.  
Analyses of Fresh and Stored Coal.  
(From Parr and Hamilton)

Vermilion County No. "7" Coal—Oakwood Nut and Slack—Calorific Power 14,410 B.Th.U. one day after mining.

Time of exposure in months.	Outdoor exposure.	Dry storage at 85°–110°F.	Wet <sup>2</sup> storage at 85°–120°F.	Submerged at 70°F.
3.....	14,200	14,050	14,150	14,400
5.....	14,050	13,800	14,000	14,400
7.....	14,150	13,875	13,950	14,400
9.....	14,025	13,900	14,025	14,400

Christian County No. "5" Coal—Pana Nut and Slack—Calorific Power 14,220 B.Th.U. three weeks after mining.

3.....	14,200	14,040	14,080	14,180
5.....	14,190	13,920	13,990	14,150
7.....	14,170	13,950	13,540	14,100
9.....	13,990	14,080	13,880	14,130

Perry County No. "6" Coal—Du Quoin Lump broken to Nut—Calorific Power 14,930 B.Th.U. one week after mining.

3.....	14,450	14,550	.....	14,930
5.....	14,130	14,300	.....	14,930
7.....	14,020	14,260	.....	14,930
9.....	14,080	14,320	.....	14,920

<sup>1</sup> Univ. of Illinois. Eng. Expt. Station, Bull. 17, 1907.

<sup>2</sup> "Drenched with water two or three times a week."

These figures show that outdoor exposure involves a loss of calorific value of from 2% to 8%. Dry (i.e. covered) storage shows no advantage over storage in the open except in the case of high sulphur coals where the oxidation of the pyrite would cause a large disintegrating effect. In most cases the losses appear to be practically complete in five months. Submerged coals show practically no loss of calorific value.

Some figures are given in the Illinois State Geological Survey year book for 1907 showing the loss of calorific value of coal samples due to weathering. Some of the samples were analysed by the Illinois State Geological Survey and others by the United States Geological Survey, but the methods of analysis were the same in both cases.

Seventeen Illinois State samples which had been six months in the laboratory showed an average loss of 365 B.Th.U. or 2.5% of the calorific value as determined from 8 United States Geological Survey samples analysed soon after collection. Another lot of 17 samples analysed six months to one year after collection showed an average loss of 365 B.Th.U. or 2.4% of the calorific value as determined in the same laboratory from 16 samples analysed within two weeks of their collection.

**White**<sup>1</sup>, in a very valuable critical study of the numerous and trustworthy ultimate analyses of coal made by the United States Geological Survey in connexion with their investigation of the fuels of the United States, proves conclusively that, "oxygen and ash are of very nearly equal anticalorific value," and that "the calorific value of coals in general is essentially indicated by the balance between the total carbon, on the one hand, and the sum of the two great impurities, oxygen and ash, on the other, the hydrogen, nitrogen, and sulphur being usually negligible, as constants."<sup>2</sup> In other words, that oxygen, even when an essential, i.e. original constituent of coal, is, in a practical sense, so much additional dead matter or ash, and should be so considered in estimating the usefulness of the coal as fuel.

He tabulates all trustworthy analyses from all parts of the United States, and from these figures draws a curve which has been reproduced as Fig. 63. In this diagram, the carbon and oxygen plus ash ratios form the horizontal, and the observed calorific values the vertical component, and of all of the 320 odd analyses tabulated, ranging from a sample of peat with 31% of oxygen, to some very high grade semi-bituminous coals and anthracites from West Virginia and Pennsylvania, none depart materially from a very clear and narrowly defined curve, and few, except weathered samples and cannels, depart by more than a fraction of one per cent. White further points out that if the analyses and calorific values are recalculated to a moisture free basis, the results again fall into a similar and equally clear curve.

The case of the cannel coals need not be discussed here; but White points out that the weathered coals invariably show marked calorific deficiencies, and low hydrogen-oxygen ratios.

<sup>1</sup>A "The effect of oxygen in coal." Bull. 29 U. S. Bureau of Mines 1911, pp. 1-80. Reprint from U. S. G. S. Bull. No. 382, 1909.

<sup>2</sup>B "The Origin of Coal." Bull. 38, U. S. Bureau of Mines, 1913, pp. 1-304.

<sup>2</sup>Variances "on account of the neglected constants—hydrogen, sulphur, and nitrogen—are rarely over 2 per cent, unless in cannels, anthracites and weathered coals." Ibid, p. 71.

White then studies the weathered samples by themselves, and finds that many of the more unstable coals weather quite appreciably, even in place underground if comparatively near the surface, and that even less susceptible coals begin to absorb oxygen as soon as opened up by mining operators, and he concludes that cases of absorption of from 10% to even 20% of oxygen may be considered "neither extraordinary nor even unusual" in semi-bituminous coals, and that lignites and peats may suffer still more. Table LVI shows two typical analyses selected by White, of cretaceous coal from near Fort Steel, Wyoming. Analysis A represents an unweathered sample from underground near the foot of a shaft; B the same sample recalculated to show the effect of the hypothetical addition of 10% of oxygen, and C the actual analysis of a weathered sample of the same coal from near the surface at an outcrop.

TABLE LVI.

**Comparison of Fresh and Outcrop Coals to show Effect of Weathering.***(White)*

No.	S	H	C	O	Ash	Mois- ture	F. C.	H. O.	Av.H.	Cal.	Curve Error
A	0.85	5.16	63.57	22.05	3.80	8.70	55.36	24.2	2.02	6310	+30
B	0.77	4.70	57.80	29.14	3.46	7.91	—	—	—	5736	—
C	0.31	4.90	59.86	29.39	4.12	9.34	55.57	18.3	1.23	5636	-219

In connexion with his study of the effect of oxygen, White considers the matter of coking, and calls attention to the fact that nearly all coking coals have a dry basis hydrogen-oxygen ratio of at least 55 per cent, and good coking coals 59 per cent or over up to the beginning of anthracitization. This conclusion is of special interest in relation to the effect of weathering on coking qualities.<sup>1</sup> White has found as already stated that weathering materially lowers the hydrogen-oxygen ratio, and as suitability for coking decreases rapidly as this ratio falls below 59 per cent, it is easy to see that a relatively small amount of weathering may produce a profound effect on the coking qualities of a coal in which this ratio is close to this limit.

<sup>1</sup> The Coals of Canada. J. B. Porter and others—Vol. I, pp. 220-1, and Vol. VI, pp. 26-7.

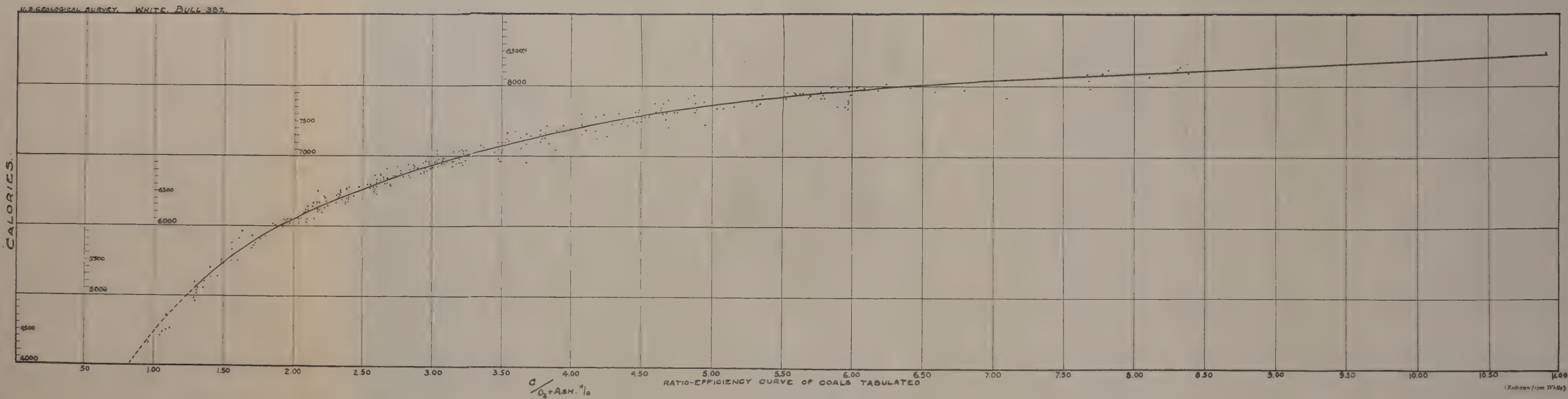


FIG. 63. Graphic record of efficiency of coals in relation to oxygen content.



## Porter, de Hart, and Billington's Studies of Old Samples of Canadian Coals.

In connexion with the author's investigation of Canadian coals it seemed desirable to carry out a series of analyses in parallel with those of Fleck and White just quoted, and thanks to the generosity of the Director of the Geological Survey, portions of nine official samples of western coals, chiefly from Alberta, were obtained from the Victoria Memorial Museum at Ottawa. Three of the samples, Nos. 7-9, were taken in 1910-11 in such a way as to represent weathered, slightly weathered, and unweathered coal from the same seam. The other samples Nos. 1-6 were much older and had been analysed and their calorific value determined thirty years ago by Dr. Hoffmann, at that time Chief Chemist to the Geological Survey. All nine samples were carefully analysed in 1912 by J. B. de Hart and E. E. Billington, research assistants of the author, and the following statement of results and conclusions is largely drawn from Mr. de Hart's report on this work.

Samples 1-6 were first studied. They were collected by members of the staff of the Geological Survey in 1881-1882 and portions were analysed at the first convenient opportunity, while other presumably similar portions were deposited in the Survey Museum. All were cretaceous coals from western Canada, one being a typical bituminous coal from Nanaimo, Vancouver Island, and the others lignitic coal, and bituminous coal proper from different parts of the Belly River and Eastern Crowsnest Pass coal fields of Southern Alberta.

Hoffmann gives detailed descriptions of the several coals, and tabulates the results of his analyses in detail in his report on the work of the Geological Survey laboratory.<sup>1</sup> He also gives details of his methods, and while more recent experiments have led chemists to adopt somewhat different methods as standard for coal analysis,<sup>2</sup> it is interesting and satisfactory to note that everything points to Hoffmann's great skill and to the substantial accuracy of his results.

The samples as obtained from Ottawa in 1912 by the author were as far as possible representative of the coals as they were exhibited in the museum, partly lump and partly fines. Each was ground to pass through 100-mesh and riffled down to about 10 grammes. The calorific values of all nine samples were determined and both proximate and ultimate analyses were made. All the determinations were made in duplicate.

The analyses were carried out in the Mining Department at McGill University exactly as described in "The Coals of Canada" volume II, page 133, et seq., except as noted below:—

*Fixed Carbon and Volatile matter.* The only difference between the method used and that given in the above mentioned report is that porcelain crucibles were used instead of platinum crucibles.

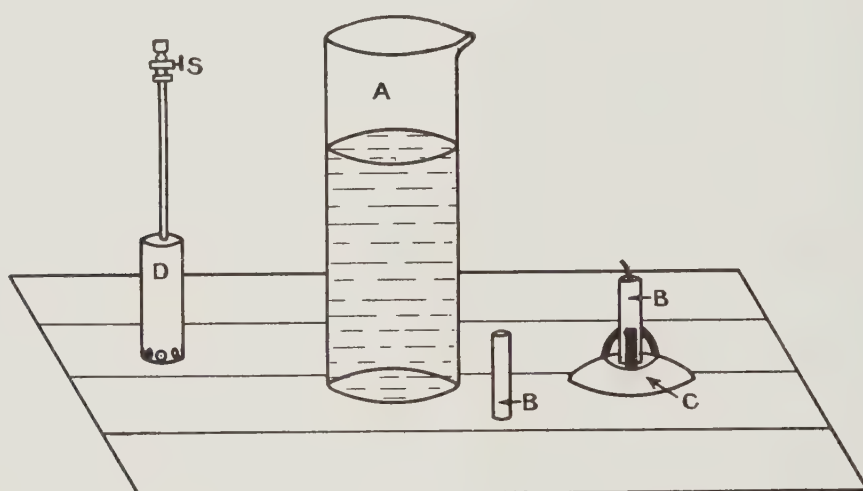
<sup>1</sup> Annual Report Geol. Survey of Canada 1882-4, part M. Coals and Lignites of the North West Territory by G. C. Hoffman, pp. 1-43 and 3 tables.

<sup>2</sup> The Coals of Canada, J. B. Porter and others—6 Vols. Dept. of Mines, Ottawa, 1912. Vol. II, p. 134.

*Carbon and Hydrogen.* For these determinations sulphuric acid absorption trains were used, the drying train comprising suitable vessels containing: (1) sulphuric acid, (2) soda lime and calcium chloride, (3) potassium hydroxide solution, (4) sulphuric acid (next the combustion tube), while the absorption train comprised: (1) sulphuric acid (next the combustion tube), (2) potassium hydroxide solution and calcium chloride, (3) sulphuric acid, (4) sulphuric acid. The last sulphuric acid bottle was used to prevent any moisture diffusing back from the aspirator bottles. In all other respects the method was similar to that given in the Coal Report.<sup>1</sup>

*Nitrogen* was determined by Kjeldahl's method. The only difference between the method used and that described in the Coal Report was that no mercury was added and consequently it was unnecessary to add sodium sulphide.<sup>2</sup>

*The calorific value* determinations were made with a Berthelot-Mahler calorimeter.<sup>3</sup> The temperatures were read as in the determinations made for the Coal Report<sup>4</sup> except that an ordinary thermometer graduated



(Porter and de Hart.)

FIG. 64. Thompson calorimeter.

to  $\frac{1}{50}$  of a degree was used instead of a Beckmann thermometer: this thermometer was read by means of a telescope. The calculations were made as in the Coal Report<sup>5</sup>.

The water equivalent of the calorimeter was determined indirectly by testing a coal whose calorific value had already been determined on the Koehler calorimeter. The method used in determining the water equivalent of the latter and the method of making all calculations is described in the Coal Report<sup>6</sup> and need not be repeated.

<sup>1</sup> The Coals of Canada, J. B. Porter and others, 6 Vols., Dept. of Mines, Ottawa, 1912, Vol. II, p. 136.

<sup>2</sup> Ibid. p. 147.

<sup>3</sup> This apparatus which is described by Thwaite in Journ. Iron and Steel Institute for 1892 is substantially identical with the Koehler Calorimeter referred to in the report cited. The Koehler apparatus is, however, slightly better in some features of its design.

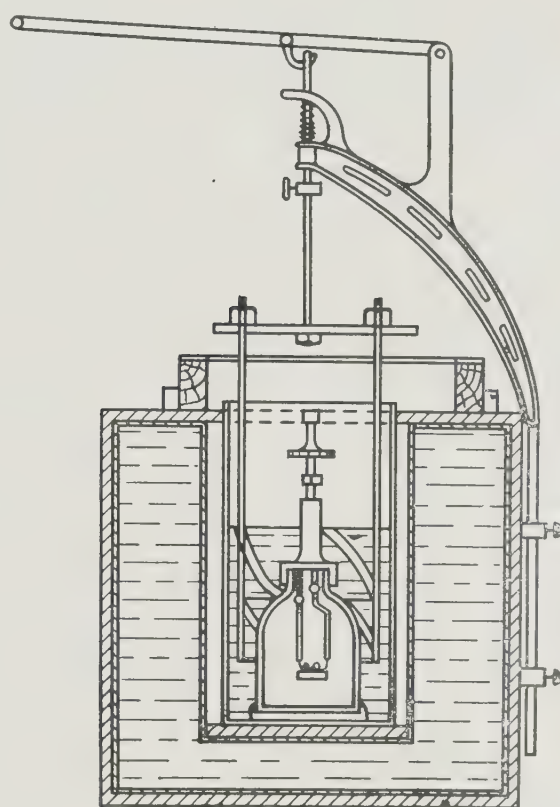
<sup>4</sup> Ibid. p. 143.

<sup>5</sup> Ibid. pp. 151-3.

<sup>6</sup> Ibid. pp. 151-4.

Hoffmann determined the calorific value of his coals in 1882-3 with the Thompson calorimeter. (See Fig. 64.) This apparatus consists of a glass vessel A, graduated to contain 2000 grammes of water, a copper cylinder B, capable of holding 2 grammes of coal and the necessary amount of fusion mixture, a brass base C, on which the cylinder is placed, and a copper cylinder D, with a row of holes round the bottom and a pipe with a stopcock S leading out of the top.

It is obviously impossible to determine the exact amounts of the errors in Hoffmann's determinations due to the use of this comparatively crude calorimeter, particularly as no figures are available as to the amount or composition of the fusion mixture used by him, or as to the exact correction which was made to compensate for "losses". In order, however, to get some



(Redrawn from Mahler.)

FIG. 65. Berthelot-Mahler calorimeter.

idea of the value of his figures, the identical calorimeter used by him was obtained from Ottawa by the courtesy of Mr. F. G. Wait of the Mines Branch, and the calorific value of a coal which had already been determined by the Berthelot-Mahler calorimeter, (Fig. 65) was re-determined by means of this Thompson instrument.

The fusion mixture recommended for the Thompson calorimeter in the text books is 3 parts of potassium chlorate to 1 part of potassium nitrate, but this mixture was found to be so fusible, that a crust formed on the top and a portion of the mixture did not burn. Hence it was necessary to use less potassium nitrate, which is the more fusible of the two salts, and a mix-

ture of 17 parts of chlorate and 3 of nitrate was successfully employed. Two grammes of finely ground coal were mixed with 20 grammes of this fusion mixture and the whole transferred to the copper cylinder, a small amount at a time, the whole being packed down evenly. About half an inch of fuse was inserted in the top. This fuse was prepared by soaking a thread of ordinary cotton wick in a strong solution of potassium nitrate and then drying it. The copper cylinder was then placed in the stand and the large cylindrical copper cover put on. The whole was put into the glass vessel and moved up and down to thoroughly stir the water.

The temperature of the water was then taken and the cylinder and stand taken out. The outside cylinder was quickly removed, the fuse lighted, the cylinder replaced and the whole immersed in the water. When the combustion was complete the stopcock was opened, the water stirred, its temperature observed, and its maximum rise recorded.

All the copper parts of the apparatus were weighed and their water equivalent calculated. The calorific value was taken as being equal to:—

$$\frac{(W + w) t}{c} - w^1$$

$W$  = weight of water taken in grammes.

$w$  = weight of water equivalent to the copper parts.

$c$  = weight of coal taken in grammes = 2 in this case.

$t$  = observed rise in temperature in degrees Centigrade.

$w^1$  = theoretical heat evolved by the burning of the fusion mixture.

Two experiments with the Thompson calorimeter were run on the same coal; they checked fairly well and the mean of the results was near enough to the value as determined by the Berthelot-Mahler instrument to give satisfactory evidences as to the substantial accuracy of Hoffmann's work.

Table LVII, p. 179, gives the results of both Hoffmann's and de Hart's analyses and calorimetric determinations, and also the theoretical calorific powers as calculated from the ultimate analyses.

The analyses made by Hoffmann do not show oxygen and nitrogen separately, but give percentages of oxygen + nitrogen. In order to be able to compare these analyses with de Hart's results two assumptions have been made: (1) the nitrogen has been assumed to have remained constant in amount, and (2) the coal has been assumed to have remained constant in weight.

The first of these assumptions is probably not very far from the truth, and as the amount of nitrogen in the coal is small compared with the oxygen, very little error will be introduced by it. The second assumption is justifiable if an attempt is made to estimate the percentage of nitrogen in Hoffmann's analyses. Some experiments were made in 1907 at McGill University, by Edgar Stansfield, on changes in weight of laboratory samples.

These samples were ground to pass through 30-mesh and were spread out in trays and left exposed to the air in a dust proof case. The trays were weighed from time to time for three years and while appreciable changes were noted, they were all very small in amount. This experiment is taken as sufficient ground for the second assumption<sup>1</sup>, which is further justified by the fact that the Museum samples were lumps over  $\frac{3}{4}$  inch in diameter instead of dust, and would consequently change at a much slower rate.

The necessity of making somewhat questionable assumptions as above in comparing analyses would be overcome if some substance in coal were found to be absolutely unaffected by weathering. It is quite probable that nitrogen or phosphorus may remain almost absolutely constant, but this fact has not yet been positively determined. It has been suggested that when samples are to be tested for weathering a known weight of gold dust should be mixed with the coal. Analyses and assays made before and after could then be compared with perfect confidence. The fatal defect in this method is the fact that it would be impossible to mix the gold dust evenly through the material and, therefore, assays of the samples taken before and after the test would be misleading.

*Descriptive list of samples analysed.*

- No. 1 Bituminous Coal—Newcastle seam Wellington mine, Nanaimo, Vancouver island, B.C.  
Seam 6 to 10 ft. thick. Sampled 1875 by Dunsmuir and Co.  
(Hoffmann, No. 33, p. M. 37, Ann. Rep. C. G. S. 1882-4.)
- No. 2 Lignitic coal—main seam at Coal Banks, Belly river, Alberta. Now Sheran's mine, Lethbridge.  
Seam  $5\frac{1}{2}$  ft. thick. Sampled 1881, G. M. Dawson.  
(Hoffmann, No. 26, p. M. 30, Ann. Rep. C. G. S. 1882-4.) (See also Dawson, Ibid, p. 70C).
- No. 3 Bituminous coal—upper seam middle fork Oldman river, Alberta. Now Lundbreck mine.  
Seam 3 ft. thick. Sampled 1881, G. M. Dawson.  
(Hoffmann, No. 30, p. M 34, Ann. Rep. C. G. S. 1882-4.) (See also Dawson, Ibid, p. 101C).
- No. 4 Bituminous coal—lower seam, middle fork Oldman river, Alberta, Now Lundbreck mine.  
Seam 3 ft. thick. Sampled 1881, G. M. Dawson.  
(Hoffmann, No. 31, p. M 35, Ann. Rep. C. G. S. 1882-4.) (See also Dawson Ibid, p. 101C).

<sup>1</sup> This second assumption, although convenient for the reasons given above, is clearly wrong as Table LVIII shows the carbon to have remained surprisingly constant when calculated to oxygen free coal, and therefore the total weight including oxygen could not have remained constant. It would have been far better to have assumed the nitrogen to have remained constant in the oxygen-ash-sulphur-moisture free coal. In either case, however, any error introduced is trifling.

- No. 5 Bituminous coal—Upper Belly river,  $25\frac{1}{2}$  miles above mouth of Waterton river, Alberta.  
Seam 1 foot thick. Sampled 1881, R. G. McConnell.  
(Hoffmann, No. 32, p. M 36, Ann. Rep. C. G. S. 1882-4.) (See also McConnell, Ibid, p. 61C).
- No. 6 Bituminous coal—Mill Creek, Alberta. Outcrop 4 miles above mill. Seam 8 to 9 ft. thick. Sampled 1882, G. M. Dawson.  
Hoffmann, No. 35, p. M 40, Ann. Rep. C. G. S. 1882-4.) (See also Dawson, Ibid, p. 99C).
- No. 7 Bituminous coal—Tunnel seam Jasper Park colliery, Alberta. Outcrop one-half mile from tunnel. Sampled 1910 D. B. Dowling.  
(See C. G. S. Summary Reports 1910, pp. 163-4, and 1911, p. 218).
- No. 8 As above, but sample taken in shaft 30 feet from surface.
- No. 9 As above, but sample taken Sept. 1911, in tunnel at distance of 1900 feet from entrance.

TABLE LVII.  
Old and Recent Analyses of Coals in Canadian Geological Survey Museum.  
(Hoffmann) (Porter and de Hart)

Coal No.....	1		2		3		4		5		6	
	1883	1912	1883	1912	1883	1912	1883	1912	1883	1912	1883	1912
Date of determination.....												
Proximate analysis:—												
Moisture.....%	2.75	1.35	6.50	4.50	3.27	2.26	2.36	1.60	3.91	3.04	1.63	1.14
Volatile matter.....%	30.95	29.15	31.59	32.16	26.41	29.45	32.07	32.08	30.93	33.03	22.61	16.31
Fixed carbon.....%	59.72	58.85	54.36	56.94	50.50	53.09	56.37	53.07	53.83	54.58	63.39	73.89
Ash.....%	6.58	10.65	7.55	6.40	19.82	15.20	9.20	13.25	11.33	9.35	12.37	8.66
Ultimate analysis:—												
Carbon.....%	72.65	68.12	65.30	62.40	59.84	62.99	71.11	66.36	66.19	65.57	71.57	72.52
Hydrogen.....%	4.89	4.56	4.30	4.68	4.17	4.87	5.04	4.70	4.43	3.83	4.05	3.73
Oxygen.....%	11.73	13.43	14.18	19.66	11.05	12.66	10.13	11.70	10.51	14.56	9.07	12.45
Nitrogen.....%	1.04	1.04	1.47	1.47	1.30	1.30	1.50	1.50	1.45	1.45	0.87	0.87
(Oxygen and nitrogen)...	12.77	14.47	15.65	21.13	12.35	13.96	11.63	13.20	11.96	16.01	9.94	13.32
Sulphur.....%	0.36	0.85	0.70	0.89	0.55	0.72	0.66	0.89	2.18	2.20	0.44	0.63
Ash.....%	6.58	10.65	7.55	6.40	19.82	15.20	9.20	13.25	11.33	9.35	12.37	8.66
Moisture.....%	2.75	1.35	6.50	4.50	3.27	2.26	2.36	1.60	3.91	3.04	1.63	1.14
Calorific value:												
Determined—B.Th.U. per lb.....	12963	11815	11133	11520	10762	11524	12635	11974	11885	11970	11885	12323
Calculated—B.Th.U. per lb.....	12700	11727	11097	10490	10460	11235	12713	11692	11648	10868	12240	11918

TABLE LVIII.  
Analyses Recalculated to Basis of Ash, Sulphur, and Moisture Free Coal.  
(Porter and de Hart)

Coal No.....	1		2		3		4		5		6	
	1883	1912	1883	1912	1883	1912	1883	1912	1883	1912	1883	1912
Date of analysis.....												
Ultimate analysis:—												
Carbon.....%	80.45	78.16	76.60	70.75	78.37	76.99	81.01	78.76	80.15	76.77	83.65	80.97
Carbon loss in 29 years..%		2.85		7.64		1.76		2.78		4.22		3.20
Oxygen.....%	12.99	15.42	16.64	22.28	14.47	15.47	11.54	13.88	12.73	17.05	10.60	13.90
Oxygen gain in 29 years. %		18.7		33.9		6.9		20.3		33.9		31.1
Hydrogen.....%	5.41	5.23	5.04	5.30	5.46	5.95	5.74	5.58	5.37	4.48	4.73	4.16
Hydrogen available.....%	3.79	3.30	2.96	2.52	3.65	4.02	4.30	3.85	3.78	2.35	3.41	2.42
Hydrogen available, loss in 29 years.....%		12.9		14.9		−10.1		10.5		37.8		29.0
Nitrogen.....%	1.15	1.19	1.72	1.67	1.70	1.59	1.71	1.78	1.75	1.70	1.02	0.97
Calorific value, determined in B.Th.U. per lb.....	14340	13520	13030	13020	14080	14050	14370	14170	14290	13910	13870	13730
Loss in 29 years.....%		5.7		0.1		0.2		1.4		2.7		1.0

TABLE LIX.  
Analyses Recalculated to Basis of Oxygen, Ash, Sulphur, and Moisture Free Coal.  
(Porter and de Harl)

Coal No.....	1		2		3		4		5		6	
	1883	1912	1883	1912	1883	1912	1883	1912	1883	1912	1883	1912
Date of analysis.....												
Ultimate analysis:—												
Carbon.....	92.46	92.41	91.89	91.03	91.63	91.08	91.58	91.45	91.84	92.55	93.57	94.04
Hydrogen.....	6.22	6.18	6.05	6.82	6.38	7.04	6.49	6.48	6.15	5.40	5.29	4.83
Nitrogen.....	1.32	1.41	2.06	2.15	1.99	1.88	1.93	2.07	2.01	2.05	1.14	1.13

### Summary and Conclusions.

A comparison of the ash determinations shows discrepancies which can only be explained by imperfect sampling. This was expected and was unavoidable as it was not permissible to destroy the whole of the Museum samples and therefore fragments had to be taken of which the best that can be said is that they were as nearly representative as possible. Fortunately, however, it has been proved by Lord that the organic constituents of any particular coal are very nearly constant throughout an extensive area, even where different samplings show large variations in the proportion of ash. If, therefore, we recalculate Table LVII on a pure coal basis, eliminating ash and moisture, or ash, moisture and oxygen, we have good ground for believing that comparison of Hoffmann's and de Hart's analyses will be much more trustworthy than if made directly on the original data. The result of this recalculation is shown in Table LVIII, but it should be noted that it has not been considered worth while to recalculate the proximate analyses.

A study of Tables LVII and LVIII shows, as might have been expected, that weathering has decreased the percentage of carbon in every case, while the percentage of oxygen has increased in every case. The question arises as to whether the decrease of carbon is due to actual loss of carbon in the form of carbon dioxide, etc., or merely to the greater weight of the sample because of its absorption of oxygen. If it were due to the latter cause alone the carbon would be constant when recalculated on an oxygen free basis. Table LIX was therefore calculated, and it shows rather surprising constancy in the carbon contents. It is true that some coals show increases and some decreases, but the variations are so small that they can easily be accounted for by the fact that, as above explained, the sampling was not above reproach. In view of this it is unsafe to draw any definite conclusions, particularly as the samples were few in number.

The available hydrogen like the carbon, shows changes varying from an increase of 0.71% to a decrease of 0.86. It is quite possible that the trouble again lies with the sampling, but these variations are interesting, and it is worthy of note that they are virtually nil when the carbon remains unchanged, but become considerable and always in a contrary sense where the carbon changes are at all considerable.

The losses in calorific power (Table LVIII) show variations from 5.7% down to almost nothing. Since the figures are on a basis of organic coal free from sulphur, ash, etc., the above loss must be an actual organic loss; in other words, a certain proportion of the carbon and hydrogen have actually disappeared in weathering as was to have been expected. In this connexion it should be noted that the largest decreases are in the mine sample No. 1, and the narrow seam No. 5; suggesting that the outcrop coal had already suffered the main part of all possible weathering before being sampled in 1882.

Table LX gives the results of a series of analyses of coals Nos. 7, 8, and 9, which were dealt with exactly as were coals Nos. 1 to 6. These

last three samples were all relatively recent, and we have no data to show what changes they have experienced since being taken, but when the samples were collected an especial attempt was made to secure three lots of material which would typify (a) natural outcrop, i.e., coal which had experienced full natural weathering for a very long period of time; (b) shallow coal, which while covered was yet within the zone of slight natural weathering, and (c) deep and hence unweathered coal.

Except as regards weathering the three samples were chosen to be as nearly as possible identical, and there is every reason to believe that they were originally virtually identical except in the matter of ash and moisture. In Table LXI, these constituents including also sulphur have been eliminated, and we thus have an apparently trustworthy indication of the effect of long continued weathering under natural conditions.

A study of these last tables, LX and LXI, and particularly the latter one, confirms the conclusion drawn from the three preceding tables, namely, that weathering, and especially natural weathering in place over very long periods of time, results in a marked decrease in carbon and available hydrogen and a corresponding decrease in calorific value, and that the change is accompanied by a large increase in the amount of oxygen.

TABLE LX.  
Analyses and calorific values of samples from Jasper Park seam.  
(Porter and de Hart)

Coal No.	7	8	9
Date of sampling at mine .....	1910	1910	1911
Proximate analysis			
Moisture.....%	5.57	0.69	0.39
Volatile matter.....%	18.80	16.25	13.72
Fixed carbon.....%	48.32	78.27	67.04
Ash.....%	27.31	4.80	18.85
Ultimate analysis			
Carbon.....%	50.26	83.84	72.03
Hydrogen.....%	2.56	4.77	3.81
Oxygen.....%	13.09	4.06	3.13
Nitrogen.....%	0.86	1.20	1.11
(Oxygen and nitrogen).....%	13.95	5.26	4.24
Sulphur.....%	0.35	0.65	0.68
Ash.....%	27.31	4.80	18.85
Moisture.....%	5.57	0.68	0.39
Calorific value			
Determined—B.Th.U. per lb.....	8,332	14,465	12,447

TABLE LXI.  
Analyses recalculated to ash, moisture and sulphur free basis.  
(Porter and de Hart)

Coal No.	Carbon %	Hydrogen %	Oxygen %	Nitrogen %	Available hydrogen %	B.Th.U. per lb. "pure coal"
7	75.40	3.84	19.61	1.29	1.65	12,414
8	89.37	5.08	4.32	1.28	4.60	15,390
9	89.90	4.75	3.90	1.39	4.31	15,735

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- †62. Mineral production of Canada, 1909. Preliminary report on—by John McLeish, B.A.
63. Summary report of Mines Branch, 1909.
67. Iron deposits of the Bristol mine, Pontiac county, Quebec. Bulletin No. 2—by Einar Lindeman, M.E., and Geo. C. Mackenzie, B.Sc.
- †68. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.
69. Chrysotile-asbestos: its occurrence, exploitation, milling, and uses. Report on—by Fritz Cirkel, M.E. (Second edition, enlarged.)
- †71. Investigation of the peat bogs and peat industry of Canada, 1909–10; to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenberg's wet-carbonizing process: from *Teknisk Tidskrift*, No. 12, December 26, 1908—translation by Mr. A. Anrep, Jr.; also a translation of Lieut. Ekelund's pamphlet entitled "A solution of the peat problem," 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. Anrep. (Second edition, enlarged.)

† Publications marked thus † are out of print.

82. Magnetic concentration experiments. Bulletin No. 5—by Geo. C. Mackenzie, B.Sc.
  83. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others.  
     Vol. I—Coal washing and coking tests.  
     Vol. II—Boiler and gas producer tests.  
     †Vol. III—  
         Appendix I  
         Coal washing tests and diagrams.  
     †Vol. IV—  
         Appendix II  
         Boiler tests and diagrams.  
     †Vol. V—  
         Appendix III  
         Producer tests and diagrams.  
     †Vol. VI—  
         Appendix IV  
         Coking tests.  
         Appendix V  
         Chemical tests.
  - †84. Gypsum deposits of the Maritime provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E. (See No. 245.)
  88. The mineral production of Canada, 1909. Annual report on—by John McLeish, B.A.
- NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1909.*
- †79. Production of iron and steel in Canada during the calendar year 1909.
  - †80. Production of coal and coke in Canada during the calendar year 1909.
  85. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1909.
  89. Proceedings of conference on explosives. (Fourth edition).
  90. Reprint of presidential address delivered before the American Peat Society at Ottawa, July 25, 1910. By Eugene Haanel, Ph.D.
  92. Investigation of the explosives industry in the Dominion of Canada, 1910. Report on—by Capt. Arthur Desborough. (Fourth edition).
  - †93. Molybdenum ores of Canada. Report on—by Professor T. L. Walker Ph.D.
  100. The building and ornamental stones of Canada: Building and ornamental stones of Ontario. Report on—by Professor W. A. Parks, Ph.D.

† Publications marked thus † are out of print.

102. Mineral production of Canada, 1910. Preliminary report on—by John McLeish, B.A.
- †103. Summary report of Mines Branch, 1910.
104. Catalogue of publications of Mines Branch, from 1902 to 1911; containing tables of contents and lists of maps, etc.
105. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.
110. Western portion of Torbrook iron ore deposits, Annapolis county, N.S. Bulletin No. 7—by Howells Frechette, M.Sc.
111. Diamond drilling at Point Mamainse, Ont. Bulletin No. 6—by A. C. Lane, Ph.D., with introductory by A. W. G. Wilson, Ph.D.
118. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.
142. Summary report of Mines Branch, 1911.
143. The mineral production of Canada, 1910. Annual report on—by John McLeish, B.A.

*NOTE.—The following parts were separately printed and issued in advance of the Annual Report for 1910.*

- †114. Production of cement, lime, clay products, stone, and other materials in Canada, 1910.
- †115. Production of iron and steel in Canada during the calendar year 1910.
- †116. Production of coal and coke in Canada during the calendar year 1910.
- †117. General summary of the mineral production of Canada during the calendar year 1910.
145. Magnetic iron sands of Natashkwan, Saguenay county, Que. Report on—by Geo. C. Mackenzie, B.Sc.
- †150. The mineral production of Canada, 1911. Preliminary report on—by John McLeish, B.A.
151. Investigation of the peat bogs and peat industry of Canada, 1910–11. Bulletin No. 8—by A. Anrep.
154. The utilization of peat for fuel for the production of power, being a record of experiments conducted at the Fuel Testing Station, Ottawa, 1910–11. Report on—by B. F. Haanel, B.Sc.
167. Pyrites in Canada: its occurrence, exploitation, dressing and uses. Report on—by A. W. G. Wilson, Ph.D.
170. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.

† Publications marked thus † are out of print.

- 184. Magnetite occurrences along the Central Ontario railway. Report on—by E. Lindeman, M.E.
- 201. The mineral production of Canada during the calendar year 1911. Annual report on—by John McLeish, B.A.

*NOTE.—The following parts were separately printed and issued in advance of the Annual Report for 1911.*

- 181. Production of cement, lime, clay products, stone, and other structural materials in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.
- †182. Production of iron and steel in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.
- 183. General summary of the mineral production in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.
- †199. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1911. Bulletin on—by C. T. Cartwright, B.Sc.
- †200. The production of coal and coke in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.
- 203. Building stones of Canada—Vol. II: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, Ph.D.
- 209. The copper smelting industry of Canada. Report on—by A. W. G. Wilson, Ph.D.
- 216. Mineral production of Canada, 1912. Preliminary report on—by John McLeish, B.A.
- 222. Lode mining in Yukon: an investigation of the quartz deposits of the Klondike division. Report on—by T. A. MacLean, B.Sc.
- 224. Summary report of the Mines Branch, 1912.
- 227. Sections of the Sydney coal fields—by J. G. S. Hudson, M.E.
- †229. Summary report of the petroleum and natural gas resources of Canada, 1912—by F. G. Clapp, A.M. (See No. 224).
- 230. Economic minerals and mining industries of Canada.
- 245. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.
- 254. Calabogie iron-bearing district. Report on—by E. Lindeman, M.E.
- 259. Preparation of metallic cobalt by reduction of the oxide. Report on—by H. T. Kalmus, B.Sc., Ph.D.

† Publications marked thus † are out of print.

262. The mineral production of Canada during the calendar year 1912. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1912.*

238. General summary of the mineral production of Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.
- †247. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.
- †256. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1912—by C. T. Cartwright, B.Sc.
257. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Report on—by John McLeish, B.A.
- †258. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.
266. Investigation of the peat bogs and peat industry of Canada, 1911 and 1912. Bulletin No. 9—by A. Anrep.
279. Building and ornamental stones of Canada—Vol. III: Building and ornamental stones of Quebec. Report on—by W. A. Parks, Ph.D.
281. The bituminous sands of Northern Alberta. Report on—by S. C. Ells, M.E.
283. Mineral production of Canada, 1913. Preliminary report on—by John McLeish, B.A.
285. Summary report of the Mines Branch, 1913.
291. The petroleum and natural gas resources of Canada. Report on—by F. G. Clapp, A.M., and others:—  
Vol. I—Technology and exploitation.  
Vol. II—Occurrence of petroleum and natural gas in Canada.  
Also separates of Vol. II, as follows:—  
Part 1, Eastern Canada.  
Part 2, Western Canada.
299. Peat, lignite, and coal: their value as fuels for the production of gas and power in the by-product recovery producer. Report on—by B. F. Haanel, B.Sc.
303. Moose Mountain iron-bearing district. Report on—by E. Lindeman, M.E.
305. The non-metallic minerals used in the Canadian manufacturing industries. Report on—by Howells Fréchette, M.Sc.
309. The physical properties of cobalt, Part II. Report on—by H. T. Kalmus, B.Sc., Ph.D.

† Publications marked thus † are out of print.

320. The mineral production of Canada during the calendar year 1913. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1913.*

315. The production of iron and steel during the calendar year 1913. Bulletin on—by John McLeish, B.A.
- †316. The production of coal and coke during the calendar year 1913. Bulletin on—by John McLeish, B.A.
317. The production of copper, gold, lead, nickel, silver, zinc, and other metals, during the calendar year 1913. Bulletin on—by C. T. Cartwright, B.Sc.
318. The production of cement, lime, clay products, and other structural materials, during the calendar year 1913. Bulletin on—by John McLeish, B.A.
319. General summary of the mineral production of Canada during the calendar year 1913. Bulletin on—by John McLeish, B.A.
322. Economic minerals and mining industries of Canada. (Revised Edition).
323. The products and by-products of coal. Report on—by Edgar Stansfield, M.Sc., and F. E. Carter, B.Sc., Dr. Ing.
325. The salt industry of Canada. Report on—by L. H. Cole, B.Sc.
331. The investigation of six samples of Alberta lignites. Report on—by B. F. Haanel, B.Sc., and John Blizard, B.Sc.
333. The mineral production of Canada, 1914. Preliminary report on—by John McLeish, B.A.
334. Electro-plating with cobalt and its alloys. Report on—by H. T. Kalmus, B.Sc., Ph.D.
336. Notes on clay deposits near McMurray, Alberta. Bulletin No. 10—by S. C. Ells, B.A., B.Sc.
338. Coals of Canada: Vol. VII. Weathering of coal. Report on—by J. B. Porter, E.M., Ph.D., D.Sc.
344. Electro-thermic smelting of iron ores in Sweden. Report on—by Alfred Stansfield, D. Sc., A.R.S.M., F.R.S.C.
346. Summary report of the Mines Branch for 1914.
351. Investigation of the peat bogs and the peat industry of Canada, 1913–1914. Bulletin No. 11—by A. Anrep.
384. The Mineral production of Canada during the calendar year 1914. Annual Report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1914.*

348. Production of coal and coke in Canada during the calendar year, 1914. Bulletin on—by J. McLeish, B.A.

- 349. Production of iron and steel in Canada during the calendar year, 1914. Bulletin on—by J. McLeish, B.A.
- 350. Production of copper, gold, lead, nickel, silver, zinc, and other metals, during the calendar year, 1914. Bulletin on—by J. McLeish, B.A.
- 383. The production of cement, lime, clay products, stone and other structural materials, during the calendar year 1914. Bulletin on—by John McLeish, B.A.
- 385. Investigation of a reported discovery of phosphate at Banff, Alberta. Bulletin No. 12—by H. S. de Schmid, M.E., 1915.
- 406. Description of the laboratories of the Mines Branch of the Department of Mines, 1916. Bulletin No. 13.
- 408. Mineral production of Canada, 1915. Preliminary report on—by John McLeish, B.A.
- 411. Cobalt alloys with non-corrosive properties. Report on—by H. T. Kalmus, B.Sc., Ph.D.
- 413. Magnetic properties of cobalt and of  $\text{Fe}_2\text{Co}$ . Report on—by H. T. Kalmus, B.Sc., Ph.D.

*The Division of Mineral Resources and Statistics has prepared the following lists of mine, smelter, and quarry operators: Metal mines and smelters, General list of mines (except coal and metal mines), Coal mines, Stone quarry operators, Manufacturers of clay products and of cement, Manufacturers of lime, and Operators of sand and gravel deposits. Copies of the lists may be obtained on application.*

#### IN THE PRESS

- 388. The building and ornamental stones of Canada—Vol. IV: building and ornamental stones of the western provinces. Report on—by W. A. Parks, Ph.D.
- 401. Feldspar in Canada. Report on—by H. S. de Schmid, M.E.
- 419. Production of iron and steel in Canada during the calendar year, 1915. Bulletin on—by J. McLeish, B.A.
- 420. Production of coal and coke in Canada during the Calendar year, 1915, Bulletin on—by J. McLeish, B.A.
- 421. Summary report of the Mines Branch for 1915.

## FRENCH TRANSLATIONS

971. (26a) Rapport annuel sur les industries minérales du Canada, pour l'année 1905.
- †4. Rapport de la Commission nommée pour étudier les divers procédés électro-thermiques pour la réduction des minerais de fer et la fabrication de l'acier employés en Europe—by Eugene Haanel, Ph.D. (French Edition), 1905.
- 26a. The mineral production of Canada, 1906. Annual report on—by John McLeish, B.A.
- †28a. Summary report of Mines Branch, 1908.
56. Bituminous or oil-shales of New Brunswick and Nova Scotia; also on the oil-shale industry of Scotland. Report on—by R. W. Ells, LL.D.
81. Chrysotile-asbestos, its occurrence, exploitation, milling, and uses. Report on—by Fritz Cirkel, M.E.
- 100a. The building and ornamental stones of Canada: Building and ornamental stones of Ontario. Report on—by W. A. Parks, Ph.D.
149. Magnetic iron sands of Natashkwan, Saguenay county, Que. Report on—by Geo. C. Mackenzie, B.Sc.
155. The utilization of peat fuel for the production of power, being a record of experiments conducted at the Fuel Testing Station, Ottawa, 1910-11. Report on—by B. F. Haanel, B.Sc.
- †156. The tungsten ores of Canada. Report on—by T. L. Walker, Ph.D.
169. Pyrites in Canada: its occurrences, exploitation, dressing, and uses.. Report on—by A. W. G. Wilson, Ph.D.
179. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.
180. Investigation of the peat bogs, and peat industry of Canada, 1910-11. Bulletin No. 8—by A. Anrep.
195. Magnetite occurrences along the Central Ontario railway. Report on—by E. Lindeman, M.E.
- †196. Investigation of the peat bogs and peat industry of Canada, 1909-10, to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenburg's wet-carbonizing process: from Teknisk Tidskrift, No. 12, December 26, 1908—translation by Mr. A. Anrep; also a translation of Lieut. Ekelund's pamphlet entitled "A solution of the peat problem," 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. Anrep. (Second Edition, enlarged.)
197. Molybdenum ores of Canada. Report on—by T. L. Walker, Ph.D.

† Publications marked thus † are out of print.

- †198. Peat and lignite: their manufacture and uses in Europe. Report on—by Erik Nystrom, M.E., 1908.
- 202. Graphite: its properties, occurrences, refining, and uses. Report on—by Fritz Cirkel, M.E., 1907.
- 204. Building stones of Canada—Vol. II: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, Ph.D.
- 219. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.
- 223. Lode Mining in the Yukon: an investigation of quartz deposits in the Klondike division. Report on—by T. A. MacLean, B.Sc.
- 224a. Mines Branch Summary report for 1912.
- †226. Chrome iron ore deposits of the Eastern Townships. Monograph on—by Fritz Cirkel, M.E. (Supplementary section: Experiments with chromite at McGill University—by J. B. Porter, E.M., D.Sc.).
- 231. Economic minerals and mining industries of Canada.
- 233. Gypsum deposits of the Maritime Provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E.
- 246. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.
- 260. The preparation of metallic cobalt by reduction of the oxide. Report on—by H. T. Kalmus, B.Sc., Ph.D.
- 263. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.
- †264. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.
- 265. Annual mineral production of Canada, 1911. Report on—by John McLeish, B.A.
- 280. The building and ornamental stones of Canada, Vol. III; Province of Quebec. Report on—by Professor W. A. Parks, Ph.D.
- 286. Summary Report of Mines Branch, 1913.
- 287. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.
- 288. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

† Publications marked thus † are out of print.

289. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Bulletin on—by John McLeish, B.A.
290. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada during the calendar year 1912. Bulletin on—by C. T. Cartwright, B.Sc.
307. Catalogue of French publications of the Mines Branch and of the Geological Survey, up to July, 1914.
308. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others.  
Vol. I—Coal washing and coking tests.  
Vol. II—Boiler and gas producer tests.  
Vol. III—  
Appendix I  
Coal washing tests and diagrams.  
Vol. IV—  
Appendix II  
Boiler tests and diagrams.
314. Iron ore deposits, Bristol mine, Pontiac county, Quebec, Report on—by E. Lindeman, M.E.
321. Annual mineral production of Canada, during the calendar year 1913. Report on—by J. McLeish, B.A.

## IN THE PRESS

292. The petroleum and natural gas resources of Canada. Report on—by F. G. Clapp, A.M., and others.  
Vol. I.—Technology and exploitation.
306. The non-metallic minerals used in the Canadian manufacturing industries Report on—by Howells Fréchette, M.Sc.
310. The physical properties of the metal cobalt, Part II. Report on—by H. T. Kalmus, B.Sc., Ph.D.

## MAPS

- †6. Magnetometric survey, vertical intensity: Calabogie mine, Bagot township, Renfrew county, Ontario—by E. Nystrom, 1904. Scale 60 feet to 1 inch. Summary report 1905. (See Map No. 249.)
- †13. Magnetometric survey of the Belmont iron mines, Belmont township, Peterborough county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1906. (See Map No. 186).
- †14. Magnetometric survey of the Wilbur mine, Lavant township, Lanark county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1906.
- †33. Magnetometric survey, vertical intensity: lot 1, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)
- †34. Magnetometric survey, vertical intensity: lots 2 and 3, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)
- †35. Magnetometric survey, vertical intensity: lots 10, 11, and 12 concession IX, and lots 11 and 12, concession VIII, Mayo township, Hastings county. Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)
- \*36. Survey of Mer Bleue peat bog, Gloucester township, Carleton county, and Cumberland township, Russel county, Ontario—by Erik Nystrom, and A. Anrep. (Accompanying report No. 30.)
- \*37. Survey of Alfred peat bog. Alfred and Caledonia townships, Prescott county, Ontario—by Erik Nystrom and A. Anrep. (Accompanying report No. 30.)
- \*38. Survey of Welland peat bog, Wainfleet and Humberstone townships, Welland county, Ontario—by Erik Nystrom and A. Anrep. (Accompanying report No. 30.)
- \*39. Survey of Newington peat bog, Osnabruck, Roxborough, and Cornwall townships, Stormont county, Ontario—by Erik Nystrom and A. Anrep. (Accompanying report No. 30.)
- \*40. Survey of Perth peat bog, Drummond township, Lanark county, Ontario—by Erik Nystrom and A. Anrep. (Accompanying report No. 30.)
- †41. Survey of Victoria Road peat bog, Bexley and Carden townships, Victoria county, Ontario—Erik Nystrom and A. Anrep. (Accompanying report No. 30.)
- \*48. Magnetometric survey of Iron Crown claim at Nimpkish (Klaanch) river, Vancouver island, B.C.—by E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47).

Note.—1. Maps marked thus \* are to be found only in reports.

2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

- \*49. Magnetometric survey of Western Steel Iron claim, at Sechart, Vancouver island, B.C.—By E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47.)
- \*53. Iron ore occurrences, Ottawa and Pontiac counties, Quebec, 1908—by J. White and Fritz Cirkel. (Accompanying report No. 23.)
- \*54. Iron ore occurrences, Argenteuil county, Quebec, 1908—by Fritz Cirkel. (Accompanying report No. 23.) Out of print.
- †57. The productive chrome iron ore district of Quebec—by Fritz Cirkel. (Accompanying report No. 29.)
- †60. Magnetometric survey of the Bristol mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)
- †61. Topographical map of Bristol mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)
- †64. Index map of Nova Scotia: Gypsum—by W. F. Jennison. } (Accompanying report No. 84).
- †65. Index map of New Brunswick: Gypsum—by W. F. Jennison. } (Accompanying report No. 84).
- †66. Map of Magdalen islands: Gypsum—by W. F. Jennison.... } (Accompanying report No. 84).
- †70. Magnetometric survey of Northeast Arm iron range, Lake Timagami, Nipissing district, Ontario—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 63.)
- †72. Brunner peat bog, Ontario—by A. Anrep. } (Accompanying report No. 71.)
- †73. Komoka peat bog, Ontario— “ “ } (Accompanying report No. 71.)
- †74. Brockville peat bog, Ontario— “ “ } (Accompanying report No. 71.)
- †75. Rondeau peat bog, Ontario— “ “ } (Out of print.)
- †76. Alfred peat bog, Ontario— “ “ } (Out of print.)
- †77. Alfred peat bog, Ontario, main ditch profile—by A. Anrep. } (Out of print.)
- †78. Map of asbestos region, Province of Quebec, 1910—by Fritz Cirkel. Scale 1 mile to 1 inch. (Accompanying report No. 69.)
- †94. Map showing Cobalt, Gowganda, Shiningtree, and Porcupine districts—by L. H. Cole. (Accompanying Summary report, 1910.)
- †95. General map of Canada, showing coal fields. (Accompanying report No. 83—by Dr. J. B. Porter.)
- †96. General map of coal fields of Nova Scotia and New Brunswick. (Accompanying report No. 83—by Dr. J. B. Porter.)
- †97. General map showing coal fields in Alberta, Saskatchewan, and Manitoba. (Accompanying report No. 83—by Dr. J. B. Porter.)

Note.—1. Maps marked thus \* are to be found only in reports.

2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

- †98. General map of coal fields in British Columbia. (Accompanying report No. 83—by Dr. J. B. Porter.)
- †99. General map of coal field in Yukon Territory. (Accompanying report No. 83—by Dr. J. B. Porter.)
- †106. Geological map of Austin Brook iron-bearing district, Bathurst township, Gloucester county, N.B.—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)
- †107. Magnetometric survey, vertical intensity: Austin Brook iron-bearing district—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)
- †108. Index map showing iron-bearing area at Austin Brook—by E. Lindeman. (Accompanying report No. 105.)
- \*112. Sketch plan showing geology of Point Mamainse, Ont.—by Professor A. C. Lane. Scale 4,000 feet to 1 inch. (Accompanying report No. 111.)
- †113. Holland peat bog Ontario—by A. Anrep. (Accompanying report No. 151.)
- \*119-137. Mica: township maps, Ontario and Quebec—by Hugh S. de Schmid. (Accompanying report No. 118.)
- †138. Mica: showing location of principal mines and occurrences in the Quebec mica area—by Hugh S. de Schmid. Scale 3.95 miles to 1 inch. (Accompanying report No. 118.)
- †139. Mica: showing location of principal mines and occurrences in the Ontario mica area—by Hugh S. de Schmid. Scale 3.95 miles to 1 inch. (Accompanying report No. 118.)
- †140. Mica: showing distribution of the principal mica occurrences in the Dominion of Canada—by Hugh S. de Schmid. Scale 3.95 miles to 1 inch. (Accompanying report No. 118.)
- †141. Torbrook iron-bearing district Annapolis county, N.S.—by Howells Fréchette. Scale 400 feet to 1 inch. (Accompanying report No. 110.)
- 146. Distribution of iron ore sands of the iron ore deposits on the north shore of the River and Gulf of St. Lawrence, Canada—by Geo. C. Mackenzie. Scale 100 miles to 1 inch. (Accompanying report No. 145.)
- †147. Magnetic iron sand deposits in relation to Natashkwan harbour and Great Natashkwan river, Que. (Index Map)—by Geo. C. Mackenzie. Scale 40 chains to 1 inch. (Accompanying report No. 145.)
- †148. Natashkwan magnetic iron sand deposits, Saguenay county, Que.—by Geo. C. Mackenzie. Scale 1,000 feet to 1 inch. (Accompanying report No. 145.)

Note.—1. Maps marked thus \* are to be found only in reports.

2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

- |       |   |                                  |
|-------|---|----------------------------------|
| †152. | Map showing the location of peat bogs investigated in Ontario—by A. Anrep. (See Map No. 354.)   | } (Accompanying report No. 151.) |
| †153. | Map showing the location of peat bogs, as investigated in Manitoba—by A. Anrep.   |                                  |
| †157. | Lac du Bonnet peat bog, Manitoba—by A. Anrep.   |                                  |
| †158. | Transmission peat bog, Manitoba— “ “  |                                  |
| †159. | Corduroy peat bog, Manitoba— “ “  |                                  |
| †160. | Boggy Creek peat bog, Manitoba— “ “   |                                  |
| †161. | Rice Lake peat bog, Manitoba— “ “   |                                  |
| †162. | Mud Lake peat bog, Manitoba— “ “  |                                  |
| †163. | Litter peat bog, Manitoba— “ “  |                                  |
| †164. | Julius peat litter bog, Manitoba— “ “   |                                  |
| †165. | Fort Frances peat bog, Ontario— “ “   |                                  |
| *166. | Magnetometric map of No. 3 mine, lot 7, concessions V and VI, McKim township, Sudbury district, Ont.—by E. Lindeman. (Accompanying Summary report, 1911.)                               |                                  |
| †168. | Map showing pyrites mines and prospects in Eastern Canada, and their relation to the United States market—by A. W. G. Wilson. Scale 125 miles to 1 inch. (Accompanying report No. 167.) |                                  |
| †171. | Geological map of Sudbury nickel region, Ont.—by Prof. A. P. Coleman. Scale 1 mile to 1 inch. (Accompanying report No. 170.)  |                                  |
| †172. | Geological map of Victoria mine—by Prof. A. P. Coleman.   | } (Accompanying report No. 170.) |
| †173. | “ Crean Hill mine—by Prof. A. P. Coleman  |                                  |
| †174. | “ Creighton mine—by Prof. A. P. Coleman.  |                                  |
| †175. | “ showing contact of norite and Laurentian in vicinity of Creighton mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)   |                                  |
| †176. | “ Copper Cliff offset—by Prof. A. P. Coleman. (Accompanying report No. 170.)  |                                  |
| †177. | “ No. 3 mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)   |                                  |
| †178. | “ showing vicinity of Stobie and No. 3 mines—by Prof. A. P. Coleman. (Accompanying report No. 170.)   |                                  |

Note.—1. Maps marked thus \* are to be found only in reports.

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- †185. Magnetometric survey, vertical intensity: Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †185a. Geological map, Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †186. Magnetometric survey, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †186a. Geological map, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †187. Magnetometric survey, vertical intensity: St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †187a. Geological map, St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †188. Magnetometric survey, vertical intensity: Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †188a. Geological map, Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †189. Magnetometric survey, vertical intensity: Ridge iron ore deposits, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †190. Magnetometric survey, vertical intensity: Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †190a. Geological map, Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †191. Magnetometric survey, vertical intensity: Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †191a. Geological map, Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †192. Magnetometric survey, vertical intensity: Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

Note.—1. Maps marked thus \* are to be found only in reports.

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- †192a. Geological map, Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †193. Magnetometric survey, vertical intensity: Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †193a. Geological map, Kennedy property, Carlow township, Hastings county Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †194. Magnetometric survey, vertical intensity: Bow Lake iron ore occurrences, Faraday township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)
- †204. Index map, magnetite occurrences along the Central Ontario railway—by E. Lindeman, 1911. (Accompanying report No. 184.)
- †205. Magnetometric map, Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman, 1911. (Accompanying report No. 303.)
- †205a. Geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario, Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman. (Accompanying report No. 303.)
- †206. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: northern part of deposit No. 2—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)
- †207. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 8, 9, and 9A—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)
- †208. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposit No. 10—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)
- †208a. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district; Ontario: eastern portion of Deposit No. 11—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)
- †208b. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district, Ontario: western portion of deposit No. 11—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)
- †208c. General geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario—by E. Lindeman, 1912. Scale 800 feet to 1 inch. (Accompanying report No. 303.)

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- †210. Location of copper smelters in Canada—by A. W. G. Wilson. Scale 197·3 miles to 1 inch. (Accompanying report No. 209.)
- †215. Province of Alberta: showing properties from which samples of coal were taken for gas producer tests, Fuel Testing Division, Ottawa. (Accompanying Summary report, 1912.)
- †220. Mining districts, Yukon. Scale 35 miles to 1 inch—by T. A. MacLean. (Accompanying report No. 222.)
- †221. Dawson mining district, Yukon. Scale 2 miles to 1 inch—by T. A. MacLean. (Accompanying report No. 222.)
- \*228. Index map of the Sydney coal fields, Cape Breton, N.S. (Accompanying report No. 227.)
- †232. Mineral map of Canada. Scale 100 miles to 1 inch. (Accompanying report No. 230.)
- †239. Index map of Canada showing gypsum occurrences. (Accompanying report No. 245.)
- †240. Map showing Lower Carboniferous formation in which gypsum occurs in the Maritime provinces. Scale 100 miles to 1 inch. (Accompanying report No. 345.)
- †241. Map showing relation of gypsum deposits in Northern Ontario to railway lines. Scale 100 miles to 1 inch. (Accompanying report No. 245.)
- †242. Map, Grand River gypsum deposits, Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 245.)
- †243. Plan of Manitoba Gypsum Co.'s properties. (Accompanying report No. 245.)
- †244. Map showing relation of gypsum deposits in British Columbia to railway lines and market. Scale 35 miles to 1 inch. (Accompanying report No. 245.)
- †249. Magnetometric survey, Caldwell and Campbell mines, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)
- †250. Magnetometric survey, Black Bay or Williams mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)
- †251. Magnetometric survey, Bluff Point iron mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)
- †252. Magnetometric survey, Culhane mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

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- †253. Magnetometric survey, Martel or Wilson iron mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)
- †261. Magnetometric survey, Northeast Arm iron range, lot 339 E.T.W. Lake Timagami, Nipissing district, Ontario—by E. Nystrom. 1903. Scale 200 feet to 1 inch.
- †268. Map of peat bogs investigated in Quebec—by A. Anrep, 1912.
- †269. Large Tea Field peat bog, Quebec “ “
- †270. Small Tea Field peat bog, Quebec “ “
- †271. Lanoraie peat bog, Quebec “ “
- †272. St. Hyacinthe peat bog, Quebec “ “
- †273. Rivière du Loup peat bog “ “
- †274. Cacouna peat bog “ “
- †275. Le Parc peat bog, Quebec “ “
- †276. St. Denis peat bog, Quebec “ “
- †277. Rivière Ouelle peat bog, Quebec “ “
- †278. Moose Mountain peat bog, Quebec “ “
- †284. Map of northern portion of Alberta, showing position of outcrops of bituminous sand. Scale  $12\frac{1}{2}$  miles to 1 inch. (Accompanying report No. 281.)
- †293. Map of Dominion of Canada, showing the occurrences of oil, gas, and tar sands. Scale 197 miles to 1 inch. (Accompanying report No. 291.)
- †294. Reconnaissance map of part of Albert and Westmorland counties, New Brunswick. Scale 1 mile to 1 inch. (Accompanying report No. 291.)
- †295. Sketch plan of Gaspé oil fields, Quebec, showing location of wells. Scale 2 miles to 1 inch. (Accompanying report No. 291.)
- †296. Map showing gas and oil fields and pipe-lines in southwestern Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 291.)
- †297. Geological map of Alberta, Saskatchewan, and Manitoba. Scale 35 miles to 1 inch. (Accompanying report No. 291.)
- †298. Map, geology of the forty-ninth parallel, 0.9864 miles to 1 inch. (Accompanying report No. 291.)

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- †302. Map showing location of main gas line, Bow Island, Calgary. Scale 12½ miles to 1 inch. (Accompanying report No. 291.)
- †311. Magnetometric map, McPherson mine, Barachois, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.
- †312. Magnetometric map, iron ore deposits at Upper Glencoe, Inverness county, Nova Scotia—by E. Lindeman, 1913. Scale 200 feet to 1 inch.
- †313. Magnetometric map, iron ore deposits at Grand Mira, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.
- †327. Map showing location of Saline Springs and Salt Areas in the Dominion of Canada. (Accompanying Report No. 325.)
- †328. Map showing location of Saline Springs in the Maritime Provinces. Scale 100 miles to 1 inch. (Accompanying Report No. 325.)
- †329. Map of Ontario-Michigan Salt Basin, showing probable limit of productive area. Scale 25 miles to 1 inch. (Accompanying Report No. 325.)
- †330. Map showing location of Saline Springs in Northern Manitoba. Scale 12½ miles to 1 inch. (Accompanying Report No. 325.)
- †340. Magnetometric map of Atikokan iron-bearing district, Atikokan Mine and Vicinity. Claims Nos. 10E, 11E, 12E, 24E, 25E, and 26E, Rainy River district, Ontario. By A. H. A. Robinson, 1914. Scale 400 feet to 1 inch.
- †340a. Geological map of Atikokan iron-bearing district, Atikokan Mine and Vicinity. Claims Nos. 10E, 11E, 12E, 24E, 25E, and 26E, Rainy River district, Ontario. By A. H. A. Robinson, 1914. Scale 400 feet to 1 inch.
- †341. Magnetometric map of Atikokan iron-bearing district, Sheet No. 1, Claims Nos. 400R, 401R, 402R, 112X, and 403R. Rainy River district, Ontario. By E. Lindeman, 1914. Scale 400 feet to 1 inch.
- †341a. Geological map of Atikokan iron-bearing district. Sheet No. 1. Claims Nos. 400R, 401R, 402R, 112X, and 403R, Rainy River district, Ontario. By E. Lindeman, 1914. Scale 400 feet to 1 inch.
- †342. Magnetometric map of Atikokan iron-bearing district. Sheet No. 2. Claims Nos. 403R, 404R, 138X, 139X, and 140X, Rainy River district, Ontario. By E. Lindeman, 1914. Scale 400 feet to 1 inch.
- †342a. Geological map of Atikokan iron-bearing district. Sheet No. 2. Claims Nos. 403R, 404R, 138X, 139X, and 140X, Rainy River district, Ontario. By E. Lindeman, 1914. Scale 400 feet to 1 inch.

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- †343. Magnetometric map of Atikokan iron-bearing district. Mile Post No. 140, Canadian Northern railway, Rainy River district, Ontario. By E. Lindeman, 1914. Scale 400 feet to 1 inch.
- †343a. Geological map, Atikokan iron-bearing district. Mile Post No. 140, Canadian Northern railway, Rainy River district, Ontario. By E. Lindeman, 1914. Scale 400 feet to 1 inch.
- †354. Index Map, showing location of peat bogs investigated in Ontario— by A. Anrep, 1913-14.
- †355. Richmond peat bog, Carleton county, Ontario— “ “
- †356. Luther peat bog, Wellington and Dufferin counties, Ontario— “ “
- †357. Amaranth peat bog, Dufferin county, Ontario— “ “
- †358. Cargill peat bog, Bruce county, Ontario— “ “
- †359. Westover peat bog, Wentworth county, Ontario— “ “
- †360. Marsh Hill peat bog, Ontario county, Ontario— “ “
- †361. Sunderland peat bog, Ontario county, Ontario— “ “
- †362. Manilla peat bog, Victoria county, Ontario— “ “
- †363. Stoco peat bog, Hastings county, Ontario— “ “
- †364. Clareview peat bog, Lennox and Addington counties, Ontario— “ “
- †365. Index Map, showing location of peat bogs investigated in Quebec— “ “
- †366. L'Assomption peat bog, L'Assomption county, Quebec— “ “
- †367. St. Isidore peat bog, La Prairie county, Quebec— “ “
- †368. Holton peat bog, Chateauguay county, Quebec— “ “
- †369. Index Map, showing location of peat bogs investigated in Nova Scotia and Prince Edward Island— “ “
- †370. Black Marsh peat bog, Prince county, Prince Edward Island— “ “
- †371. Portage peat bog, Prince county, Prince Edward Island— “ “
- †372. Miscouche peat bog, Prince county, Prince Edward Island— “ “
- †373. Muddy Creek peat bog, Prince county, Prince Edward Island— “ “
- †374. The Black Banks peat bog, Prince county, Prince Edward Island— “ “

† Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

- †375. Mermaid peat bog, Queens county, Prince Edward Island.....by A. Anrep, 1913-14
- †376. Caribou peat bog, Kings county, Prince Edward Island— “ “
- †377. Cherryfield peat bog, Lunenburg County, Nova Scotia— “ “
- †378. Tusket peat bog, Yarmouth county, Nova Scotia— “ “
- †379. Makoke peat bog, Yarmouth county, Nova Scotia— “ “
- †380. Heath peat bog, Yarmouth county, Nova Scotia— “ “
- †381. Port Clyde peat bog, Shelburne county, Nova Scotia— “ “
- †382. Latour peat bog, Shelburne county, Nova Scotia— “ “
- †383. Clyde peat bog, Shelburne county, Nova Scotia— “ “
- †387. Geological map Banff district, Alberta, showing location of phosphate beds—by Hugh S. de Schmid, 1915. (Accompanying report No. 385.)
- †390. Christina river map showing outcrops of bituminous sand along Christina valley; contour intervals of 20 feet—by S. C. Ells, 1915. Scale 1,000 feet to 1 inch.
- †391. Clearwater river map, showing outcrops of bituminous sand along Clearwater valley; contour intervals of 20 feet—by S. C. Ells, 1915. Scale 1,000 feet to 1 inch.
- †392. Hangingstone-Horse rivers, showing outcrops of bituminous sand along Hangingstone and Horse River valleys: contour intervals of 20 feet—by S. C. Ells, 1915. Scale 1,000 feet to 1 inch.
- †393. Steepbank river, showing outcrops of bituminous sand along Steepbank valley; contour intervals of 20 feet—by S. C. Ells, 1915. Scale 1,000 feet to 1 inch.
- †394. McKay river, 3 sheets, showing outcrops of bituminous sand along McKay valley; contour intervals of 20 feet—by S. C. Ells, 1915. Scale 1,000 feet to 1 inch.
- †395. Moose river, showing outcrops of bituminous sand along Moose valley; contour intervals of 20 feet—by S. C. Ells, 1915. Scale 1,000 feet to 1 inch.

*Address all communications to—*

DIRECTOR MINES BRANCH,  
DEPARTMENT OF MINES,  
SUSSEX STREET, OTTAWA.

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